STRENGTH CHARACTERISTICS OF FIBRE REINFORCED COMPACTED POND ASH

A THESIS SUBMITTED IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology
in
Civil Engineering

By

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NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA
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CERTIFICATE

This is to certify that the thesis entitled **"STRENGTH CHARACTERISTICS OF FIBRE REINFORCED COMPACTED POND ASH"** submitted by **Mr. ALOK SHARAN** in partial fulfilment of the requirements for the award of **Master of Technology** Degree in **Civil Engineering** with specialization in **Geo-Technical Engineering** at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree or diploma.

Date:

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SYNOPSIS

At present about 130 million tonnes of ash is being produced annually from the coal based thermal power plants in India. The power requirements of the country are rapidly increasing in pace with in industrial developments. Nearly, 73% of India's total installed power generation capacity is thermal of which coal based generation are nearly 90% (by diesel, wind, gas and steam adding about 10%). Indian coal gives 35 to 45% ash which is responsible for large volumes of pond ash. Construction of large ash disposal areas results in resettlement issues and loss of agricultural production, grazing land and habitat as well as other hand use impacts from diversion of large areas of land to waste disposal. The current practice in most of the power plants is to use large ash ponds, and nearly 75,000 acres of land is presently occupied by ash ponds sometimes in excess of 80,000 acres, which usually involves resettlement issues. Since, land holdings are typically small in size; a large ash pond development can cause hardships through loss of land-based subsistence and livelihood for literally thousands of people.

Considering these factors, effective utilization of pond ash in geo-technical constructions as a replacement to conventional earth materials needs special attention. The inherent strength of the compacted pond ash mass reduces considerably due to saturation. In this context to improve and retain the strength of compacted pond ash, cementing agents like cement or lime may be very much beneficial. The stress-strain behavior of compacted pond ash mass can be modified by inclusion of fibre reinforcements. Fibre reinforcements also improve the strength characteristics of the mass. Although, the use of reinforced earth materials has been widely accepted in many areas like embankments, foundations medium, railroads, retaining walls but the utilization of pond ash in place of earth material has not drawn much attention of researchers.

The present work aims at evaluating the geo-engineering properties of compacted pond ash and also the effectiveness of fibre inclusions in the strength characteristics of compacted pond ash specimens through a series of shear test, unconfined compression test and CBR test. For this purpose, a polyester fibre (Recron-3s) of 6mm and 12mm in length size is used with the pond ash, collected from Rourkela Steel Plant (RSP). The fibre content was varied as 0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.75, and 1.0% of the dry weight of pond ash. The effect of fibre reinforcement on compacted density has been studies using the light and heavy compaction test. Compressive strength and shear strength behaviour of compacted samples were studied using unconfined compressive strength test and direct shear test respectively. The suitability of compacted pond ash fibre mixes as a road base and sub-base material have been studied by conducting laboratory CBR tests. The results have been interpreted in terms of stress-strain behavior, variation of failure stress, variation of failure strain, effect of degree of saturation, effect of fibre content, strength ratio, and secant modulus and strength parameters and are presented in this thesis.

Based on the experimental findings the following conclusions are drawn:

- The pond ash consists of grains mostly of fine sand to silt size with uniform gradation of particles. The specific gravity of particles is lower than that of the conventional earth materials.
- An increase in compaction energy results in closer packing of particles resulting in an increase in dry density where as the optimum moisture content decreases.
- Dry unit weight of compacted specimens is found to change from 10.90 to 12.70kN/m^3 with change in compaction energy from 357 to 3488kJ/m^3, whereas the OMC is found to decrease from 38.82 to 28.09%.

- Both the unit cohesion and angle of internal friction increase with increase in compaction energy. A nonlinear relation between these parameters is found to exist with compaction energy.
- For unreinforced compacted pond ash specimens, the value of unit cohesion increases with degree of saturation up to the OMC and thereafter the same decreases. The highest value of unit cohesion occurs at OMC for samples compacted both at standard and modified densities. However, there is a continuous decrease of angle of internal friction value with degree of saturation. Initially there is a sharp decrease which gets stabilized at moisture contents higher than OMC.
- The unit undrained cohesion of reinforced specimens is found to increase with the fibre content. However, the rate of increase of unit undrained cohesion with fibre content is not linear. Initially the rate of increase is high thereafter the increase in unit cohesion is not that prominent.
- For a given compacted density and fibre content, the 12mm size fibre gives higher strength than 6mm size fibres.
- The highest value of unconfined compressive strength is found to be 12kPa and 29kPa at a degree of saturation of 13% and 14 % for samples compacted at standard and modified proctor density. Moisture content either higher or lower than the said value results in decrease in the compressive strength.
- The failure stresses as well as initial stiffness of unreinforced samples, compacted with greater compaction energies, are higher than the samples compacted with lower compaction energy. However the failure strains are found to be lower for samples compacted with higher

energies. The failure strains vary from a value of 0.75 to 1.75%, indicating brittle failures in the specimens.

- An almost linear relationship is found to exist between the compaction energy and unconfined compressive strength.
- The UCS value of unreinforced specimens is found to change from 1.2 to 17.0kPa with change in compaction energy from 357 to 3488kJ/m^3 indicating that the strength can be modified suitably by changing the compactive effort. It revealed from the test results that a linear relationship exists between the initial tangent modulus with unconfined compressive strength and deformation modulus.
- The trend observed in the CBR value with moisture content is very much similar to that observe with unconfined compressive strength value of specimens. This shows that for a given compacted dry density higher unconfined compressive strength as well as CBR value can be obtained with moulding water content much lower than the OMC value.
- At low strain levels the bearing resistance is found to remain almost constant with fibre content. However at higher strain level the bearing resistance is found to increases substantially with increase in fibre content. It is observed that for a given compacted density an increase in fibre content results in decrease of initial stiffness whereas the failure strain increases.
- The inclusion of fibre gives ductility to the specimens. The reduction in post peak stress of a reinforced sample is comparatively lower than the unreinforced sample.

The strength parameters achieved in the present study is comparable to the good quality, similar graded conventional earth materials. Hence, it can be safely concluded that reinforced pond ash can replace the natural earth materials in geo-technical constructions.

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LIST OF NOTATIONS

The principal symbols used in this thesis are presented for easy reference. A symbol is used for different meaning depending on the context and defined in the text as they occur.

NOTATION	**DESCRIPTION**
E	Compaction Energy, kJ/m^3
OMC	Optimum Moisture Content, %
MDD	Maximum Dry Density, kN/m^3
c_u	Unit Cohesion, kN/m^2
Φ	Angle of Internal Friction, degrees
UCS	Unconfined Compressive Strength, kN/m^2
F S	Failure Strain, %
S L	Strain Level, %
F C	Fibre Content, %
B R	Bearing Resistance, kN/m^2
M.C	Moisture Content, %
CBR	California Bearing Ratio, %
Es50	Secant Modulus, kN/m^2
Ei	Initial Tangent Modulus, kN/m^2
C'/C	Normalized Cohesion
C_u	Coefficient of uniformity
C_c	coefficient of curvature
G	Specific Gravity
NUCS	Normalized Unconfined Compressive Strength

CHAPTER -1
INTRODUCTION

INTRODUCTION

1.1 INTRODUCTION

Over the last few years, environmental and economical issues have stimulated interest in the development of alternative materials and reuse of industrial waste/by-products that can fulfill specification. A material such as pond ash is a residue collected from ash pond near thermal power plants. Pond ash is a non-plastic and lightweight material having the specific gravity relatively lower than that of the similar graded conventional earth material. Pond ash is a fine-coarse, glass powder recovered from the gases of burning coal during the production of electricity. These micron-sized earth elements consist primarily of silica, alumina and iron. Massive generation of pond ash by thermal power plants has become a major cause of concern for people living in and around thermal power plants. The current rate of generation of coal ash in India has reached 130 million tons per annum with about 75,000 acres of precious land under the cover of abandoned ash ponds. It is estimated that the generation of pond ash from coal fired generation units in India will reach 170 million tons per annum by the year 2012 whereas, the current rate of utilization of ash is about 35%. This leads to an ever increasing ponding area for storing ash and related environmental issues. On the other hand, the construction of highways and roads in India, which has taken a boom in the recent years, requires a huge amount of natural soil and aggregates. To meet this demand ruthless exploitation of fertile soil and natural aggregate is being adopted. This has brought the situation to an alarming state. To address these problems pond ash has been tried in the low lying areas as structural fills and embankment construction for highways. However, due to lack of sufficient knowledge and confidence its use has not taken momentum. The basic and essential parameters of pond ash, to be used either as structural fill or embankment material.

The use of reinforcement in improving the strength parameters of geo-materials has taken momentum due to the availability of variety of synthetic materials commercially at cheaper rates. The basic principles involved in earth reinforcement techniques are simple and have been used by mankind for centuries. One of the essential characteristics of reinforced soil is that it is made with two types of elements, soil grains and reinforcements. The basic mechanism of reinforced earth involves the generation of frictional forces between the soil and reinforcement. By means of friction the soil transfers the forces developed in earth mass to the reinforcement thus developing tension. The earth develops pseudo cohesion in the direction in which reinforcement is placed and the cohesion is proportional to tension developed in reinforcement.

Some research work has been carried out to find the suitability of compacted pond ash in geotechnical construction like embankments, retaining walls, structural fills, etc However, these structures are to be protected from getting wet in order to preserve the inherent strength of the compacted pond ash, which is difficult task in field situations. Keeping this in view the pond ash sample has been modify the stress-strain behaviour of destabilized material, fibre reinforcement in the form of recron- 3s were used. The effect of fibre reinforcement on the stress-strain behaviour, strength parameters of compacted mixes has been evaluated through a series of unconfined compression tests, direct shear test, CBR test. The test results show that the inclusions of fibre reinforcement are very efficient in increasing the failure load. The stabilized pond ash has distinct advantages as there is a little loss of strength due to wetting. Hence, it can be used in large scale geo-technical construction like base and sub-base courses of roads, airport pavements, retaining walls, and embankments, structural landfills in conjunction with suitable reinforcements.

1.2 HISTORICAL BACKGROUND

1.2.1Early Practices

Soil specially cohesion less material like gravel, sand and coarse silt cannot take even low stress in tension and fails instantaneously. The early man has known this phenomenon from intuition. Men used woven reeds in making sun dried bricks in ancient times even prior to Christian era. Fibrous materials like vines and papyrus are used in earth structures and mud walls in Egypt and Babylon. In the construction of the Great Wall of China where are used extensively, branches of trees were used as reinforcement in the construction of Agar-Quif ziggurat near Baghdad. Romans who developed a high degree of engineering skills in construction to meet the civic needs and military requirements built reed reinforced earth leaves along the river Tiber. Wharf walls in England also were constructed by Romans using wooden scantling as earth reinforcement. In the last century Col. Palsey introduced reinforced earth for military construction in British army. The Dutch used reinforced earth by faggoting for sea protective works.

1.2.2 Modern Development

The modern approach to reinforced earth techniques was first introduced in France and USA. In 1925, the concept was first introduced by Monster. The structure built was retaining wall with reinforced earth, wood was used as reinforcement. In the early fifties, the French constructed retaining walls constructed of granular fill with membrane. This cladding membrane was anchored with flexible ties. The first major work on reinforced earth was introduced in large scale from 1964 onwards both in USA and Europe and this was followed by detailed experimental and theoretical investigation to study the mechanism of the reinforced earth in France. This programmed was introduced by Henry Vidal and François Schlosser and the scientific approach to the study of reinforced earth structures can be said to have opened up since then.

However steel was used as reinforcement in the form of stripes which when exposed to aggressive environment like humidity, access to oxygen and exposure to corrosive agents rusts rapidly. But with the introduction of such manmade fibres like nylon, propylene and other forms of organic stable polymers which can withstand ultra-violet light rays and resistant to acid in industrial applications, the deficiency suffered by steel has greatly been overcome. With the introduction of such manmade fibres which are found to be superior to natural fibres and steel it is now feasible to build reinforced earth structure even in soil and environment aggressive to steel reinforcement.

1.3 PRINCIPLES OF REINFORCED EARTH

Soil mass is generally a discrete system consisting of soil grains and is unable to withstand tensile stresses and this is particularly true in the case of cohesion less soil like sand. Such soils cannot be stable on steep slopes and relatively large strains will be caused when external loads are imposed on them. Reinforced earth is a composite material, a combination of soil and reinforcement suitably placed to withstand the development of tensile stresses and also to improve the resistance of soil in the direction of greatest stress. The presence of reinforcement modifies the stress filed giving a restraint mostly in the form of friction or adhesion so that less strains are induced and tension is avoided. Inclusions like discrete shot fibres placed random or in different layers will also impart additional resistance by way of cohesion and friction, but these are not included in the Vidal’s concept of reinforced earth.

1.4 EFFECT OF REINFORCEMENT ON SOIL

1.4.1Force transfer from soil to reinforcement

Fig. 2.1 shows cohesion less soil mass reinforced by a flat strip. The force at the two ends of the strip is not same when there is transference of force by friction to the soil mass (Vidal, 1969). If the average cortical stress in the soil is σ_v in the region, the difference between the forces at the ends of a reinforcing element AB of length 'dl' is given by

$$dP = \sigma_v \,.\, 2w.\ dl.\ \tan \Phi_u \ldots\ldots (2.1)$$

where, 'w' is the width of the reinforcement and is Φ_u the angle of friction between the reinforcement and the soil.

Therefore, if we consider a soil mass with spacing at spacing of 'Δh' and 'Δv' as shown in the Fig. 2.2 the effect of this reinforcement on the soil mass will be to restraint by imposing an additional stress of

$$\Delta\sigma_3 = \Delta h \, (dp/\Delta v) \ldots\ldots (2.2)$$

in the horizontal direction on face AD over that prevailing on face BC.

This restraint on the soil mass increases the resistance of the soil to failure under applied stresses and the result interpreted in two related ways.

1.4.2 Equivalent confining stress concept

Fig 2.3 (a) shows the comparison of failure stresses on two soils, one unreinforced and the other reinforced. The increase in the deviator stress is seen to be $\Delta\sigma_3$ times Kp, where Kp is the coefficient of passive earth pressure equal to $\tan^2 (45 + \Phi/2)$ and $\Delta\sigma_3$ is the equivalent confining stress on sand imposed by the reinforcement (Yang, 1972).

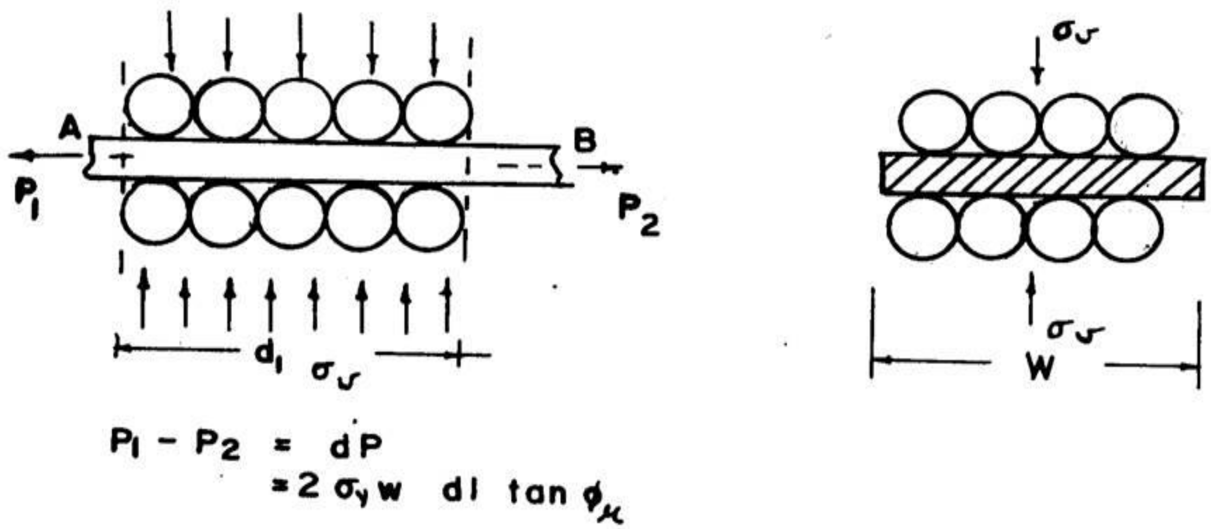

Fig. 1.1 Stress Transfer by Soil Reinforcement

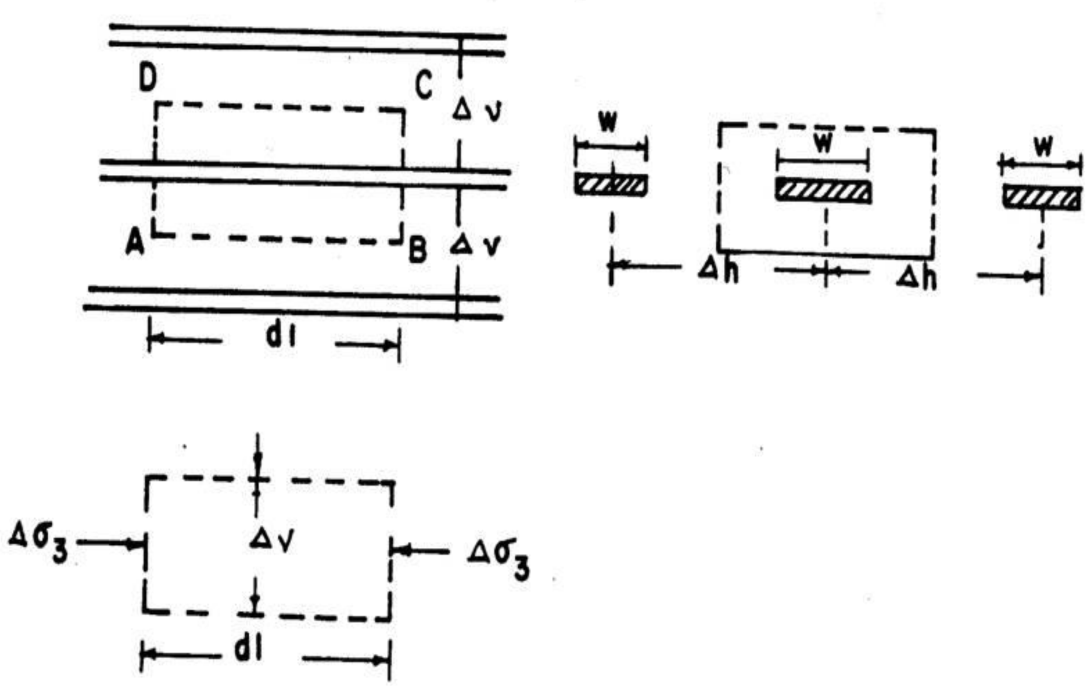

Fig 1.2 Confining Stress on Soil by Reinforcement

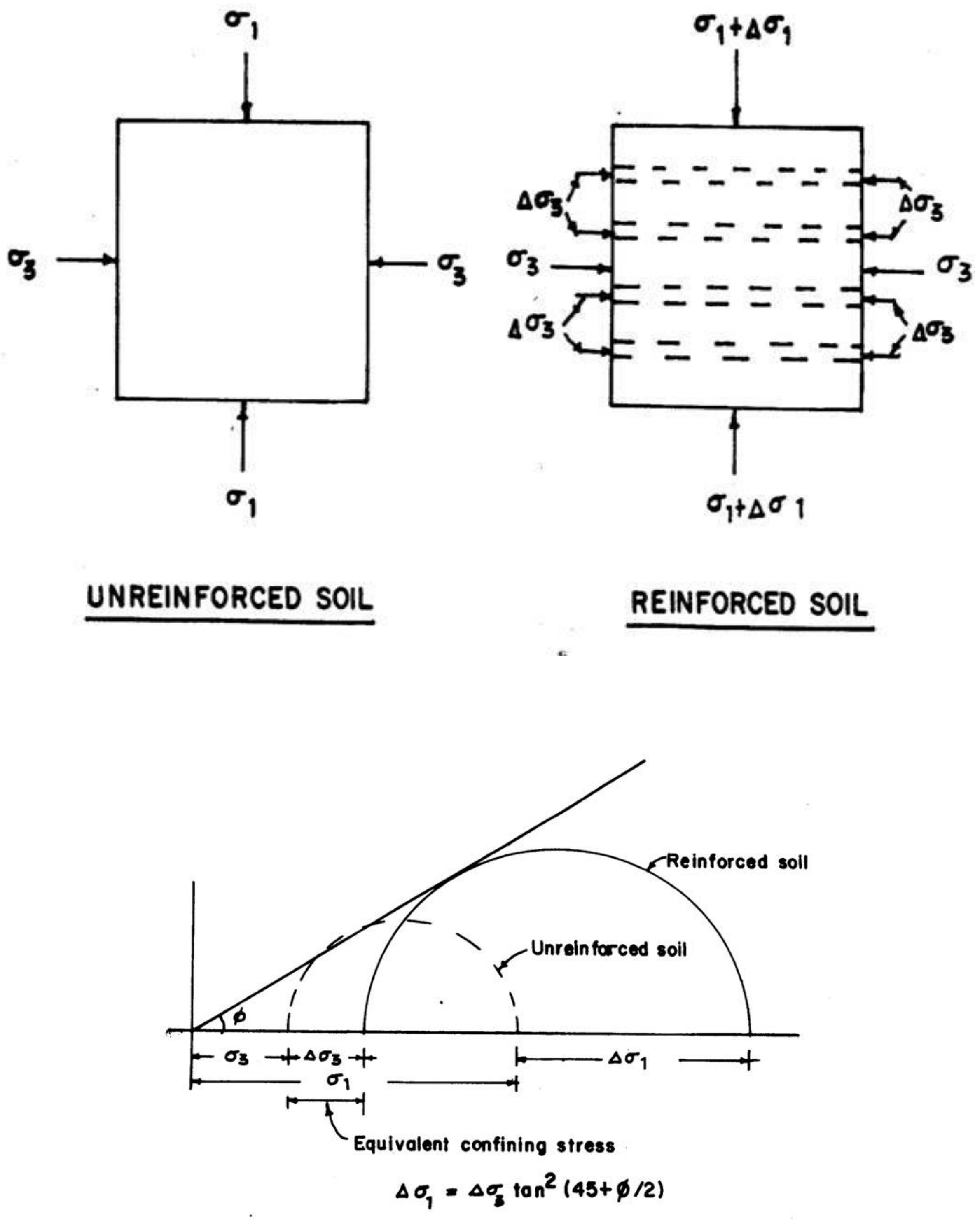

Fig 1.3 Equivalent Confining Stress Concept

1.4.3 Pseudo – Cohesion Concept

This concept (Schlosser and Long, 1974) proposes that the reinforcement induces an anisotropic or pseudo-cohesion to the soil which depends on the spacing and strength of the reinforcement. Fig. 2.3 (b) shows the approach. The increase in deviator stress at failure is

$\Delta\sigma_1 = 2c \tan (45 + \Phi/2)$…………………………………………………..... (2.3)

where, 'c' is the pseudo-cohesion induced in the soil and Φ is the angle of friction. Both the equivalent confining stress concept and the pseudo-cohesion concept are linked to the stress induced in the reinforcement. If α_f is the force in the reinforcement per unit width of the soil mass and Δv is the vertical spacing.

$\alpha_f / \Delta v$ is the equivalent confining pressure $\Delta\sigma_3$

and $\Delta\sigma_1 = (\alpha_f / \Delta v) \tan^2 (45 + \Phi/2)$

or $\Delta\sigma_1 = 2c \tan (45 + \Phi/2)$ which yields

$c = (\alpha_f / 2\Delta v) \tan (45 + \Phi/2)$……………………………………………………... (2.4)

The value of α_f is equal to the tensile strength of the reinforcement, if the reinforcement fails by breakage or the maximum force transferred by the friction between the soil and reinforcement pulls off.

In the above concept outlined, it is necessary that the reinforcement layer must be close enough so that there is effective transfer of stress by friction or adhesion as the case may be and hence the granular soils of high relative density are particularly suitable for use in reinforced earth. The concept outlined above can also hold good for cohesive soils to a very limited extent only since the adhesion of the clay to the reinforcement is small and its effect on reinforcement is small and its effect on restraint doesn't have a multiplying effect as in granular materials. Fig 1.4 shows the increase in strength at failure of an untrained clay sample with reinforcement.

1.5 REINFORCING MATERIALS

1.5.1 General

A number of materials have been reported to be successfully used as reinforcements such as steels, geofabrics, geogrids, aluminum, glass fiber, wood, rubber and concrete. In developed countries polypropylene based synthetic fibers and grids are now preferred due to their available with desired properties and durability. The durability of reinforcing materials is shown in Table 1.1. However, they are yet to be used widely in India as they are more costly. The reinforcement may take the form of strips, grids, sheet materials, rope and other combinations. The major requirements of the reinforcing materials are strength, durability, ease of handling, high adhesion or friction with soil and availability at low-cost.

The man made polymers are highly restraint to bacteria, alkalis and acid. Degradation characteristics of polymers are indicated in Table 1.2. Polyamides have a very good mechanical characteristic including excellent resistance to abrasion and absolute imperviousness to rotting. It can withstand high temperature without its performance being affected. However, their performance deteriorates on wetting.

Table 1.1Durability of Reinforcing Materials

Reinforcing Material	PH Value		Maximum Chloride ion content	Maximum Total Sulphate (SO_3)	Maximum resistivity (ohm/cm)
	Min	Max			
Aluminium	6	8	0.05	0.5	3000
Copper	5	9	0.05	0.5	2000
Galvanised steel	6	9	0.05	0.5	5000
Stainless Steel	5	10	0.05	0.5	3000
Geotextiles	-	-	-	Not affected	-
Geogrid	-	-	-	Not affected	-

Polyesters have very good resistance to abrasion and its behaviour in water is satisfactory. It has high modulus of elasticity and has only negligible creep. It can also withstand considerable temperature increase.

Polypropylene is also rot-proof, water and most chemical reagents do not affect its performance. It has only fair resistance to abrasion and is affected by temperature increase. It has only a tendency to creep. However, a majority of geo-fabrics is manufactured from polypropylene.

For use as a reinforcing material, the geo-fabrics should possess a high modulus elasticity, low elongation and satisfactory puncture strength. For use as an asphalted overlay material, adsorption qualities may also be essential.

Table 1.2 Degradation Resistances of Various Synthetic Fibres

Resistance to attack by	**Types of Synthetics**				
	Polyester	**Polyamide**	**Polyethylene**	**Polypropylene**	**PVC**
Fungus	Poor	Good	Excellent	Good	Good
Insects	Fair	Fair	Excellent	Fair	Good
Vermin	Fair	Fair	Excellent	Fair	Good
Mineral	Good	Fair	Excellent	Excellent	Good
Alkalies	Fair	Good	Excellent	Excellent	Good
Dry heat	Good	Fair	Fair	Fair	Good
Moist heat	Fair	Good	Fair	Fair	Fair
Oxidizing agent	Good	Fair	Poor	Good	-
Abrasion	Excellent	Excellent	Good	Good	Excellent
Ultraviolet light	Excellent	Good	Fair	Good	Excellent

Resistance to ultraviolet radiations and surface conformity should be considered for all jobs.

Soil has used as a construction material from times immortal. Being poor in mechanical properties, it has been putting, challenge to civil engineering’s to improve its properties depending upon the requirement which varies from site to site and economic constrains. There are many techniques employed to improve the engineering and mechanical properties of soil can be put into five major categories:

(a) Soil stabilization

(b) Reinforced earth

(c) Soil nailing

(d) Texsol

(e)Fiber reinforced oil or ply soil

1.5.2 Fibre Reinforced Soil (Ply Soil)

Randomly distributed fibres reinforced soil –termed as RDFS is among the latest ground improvement techniques in which fibres of desired type and quantity are added in soil, mixed randomly and laid in the position after compaction. Thus, the method of preparation of RDFS is similar to conventional stabilization techniques. RDFS is different from the other soil – reinforcing methods in its orientation. In reinforced earth, the reinforcement in the form of strips, sheets, etc. is laid horizontally at specific intervals, where as in RDFS fibres are mixed randomly in soil thus making a homogenous mass and maintain the isotropy in strength. Modern geotechnical engineering has focused on the use of planar reinforcement (e.g. metal strips, sheet of synthetic fabrics). However reinforcement of soil with discrete fibres is still a relatively new technique in geotechnical project.

Concepts involving the reinforcement of soils using fibres have been used since ancient times. For example, early civilizations added straws and plant roots to soil bricks to improve their properties, although the reinforcing mechanism may have not been fully understood. While building the Great Wall of China, the clay soil was mixed with tamarisk branches. The ancient method of addition of straw of wheat locally called “Turi” to the clay mud plaster is still very popular in villages. Improvement of soil by trees roots is similar to the work fibres. Gray (1947, 1978), Waldron (19770 and Wu et al. (1988) reported that plant roots increase the shear strength of the soil and, consequently the stability of natural slopes. Synthetic fibres have been used since the late 1980s, when the initial studies using polymeric fibres were conducted. Specially, triaxial compression tests, unconfined compression tests, direct shear tests and CBR tests had been conducted to study the effect of fibre reinforcement on strength characteristics and other engineering properties of RDFS. During last twenty –five years, much work has been done on strength deformation behavior of RDFS and it has been established beyond doubt that addition of fibre in soil improves the overall engineering performance of soil. Among the notable properties that improve are greater extensibility, small loss of post peak strength, isotropy in strength and absence of planes of weakness. RDFS has been used in many civil engineering projects in various countries in the recent past and the further research is in progress for many hidden aspects of it. RDFS is effective in all types of soil (i.e .sand, silt and clay)

1.5.3 Advantages of Fibre-Reinforced Soil

Randomly distributed fiber reinforced soil (RDFS) offers many advantages as listed below:

- Increased shear strength with maintenance of strength isotropy.
- Beneficial for all type of soils (i.e. sand, silt and clay).
- Reduce post peak strength loss.
- Increased ductility.
- Increased seismic performance.
- No catastrophic failure.
- Great potential to use natural or waste material such as coir fibers, shredded teire and recycled waste plastic strips and fibers.
- Provide erosion control and facilitate vegetation development.
- Reduce shrinkage and swell pressure of expansion soil.
- No appreciable change in permeability.
- Unlike lime, cement and other chemical stabilization methods, the construction using fiber – reinforcement is not significantly affected by weather conditions.
- Fiber-reinforcement has been reported to be helpful in eliminating the shallow failure on the slope face and thus reducing the cost of maintenance.

1.5.4 Basic Mechanism of RDFS

Randomly oriented discrete inclusions incorporated into soil improve its load – deformation behavior by interacting with the soil particles mechanically through surface friction and also by interlocking. The function of the bond or interlock is transfer the stress from the soil to the discrete inclusions by mobilizing the tensile strength of discrete inclusion. Thus, fiber-reinforcement works as frictional and tension resistance elements.

1.5.5 Types of Fibre

Fibers can be classified in two categories: Synthetic fiber and natural Fiber. Some commonly used fibers are coconut fiber, Sisal fiber, jute, fiber, Cotton fiber, wool fiber, Asbestos fiber, and metallic fiber and Glass fiber.

- **Synthetic Fibres**

The various types of synthetic fiber are polypropylene, nylon, plastic, glass asbestos etc. These are preferred than the natural fibers because of their higher strength and resistance. Polypropylene fiber are resistant to acidic, alkaline and chemicals (Setty and Rao, 1987). These fibers are high tensile strength, resistance to sea water and high melting point i.e. 1650C.

Polyimide has inherent defect of getting affected by the ultraviolet rays from sun but as the fibre are enbeded they are not affected. An experience fibre, no chemical changes has been detected. Synthetic fibers also show a great biological resistance. Polypropylene fibers are prone to fire and sun light which practically cannot reach inside the soil.

The important properties of polypropylene are; its versatility, excellent chemical resistance, low density, high melting point and moderate cost. All these make it an important fibre in construction applications. So far as fibre structure of polypropylene is concerned, fibers are composed of crystalline and non- crystalline regions. Fibre spinning and rawing may cause the orientation of both crystalline and amorphous regions. The degree of crystallinity of polypropylene fibre is generally between 50-60%, depending on processing conditions. Crystallization occurs between glass transition temperature and equilibrium melting temperature point. Polypropylene fibres are being used extensively throughout the USA and

Canada in all types of concrete construction, and they have proven to be an effective method of controlling un-using and troublesome shrinkage cracking in concrete. Polypropylene fibres were tested in eight different media (distilled water, iron, bacteria culture, seawater and soil) for seventeen months and found no degradation. Results showed that there was no change in tensile strength. Plastic fibres show loss in strength with temperature. Nylon is comparable with polypropylene as for as strength, chemical innerness and durability is concerned. Steel fibres are prone to rust and acids. Glass fibres although costly but they can bear temperature up to 1500 F. Asbestos, glass, carbon fibre have been found to be resistant to alkaloids and other chemicals attack. But long exposure to adverse environment, asbestos fibres has been found to lead to corrosion damage.

- **Natural Fibres**

The various types of natural fibre available in India are: coir, sisal, jute, bhabar, hemp, munja, bamboo and banana. In order to minimize the cost of ply soil, locally available fibres should be considered in design. But at the same time stability and life of structure should be given prime importance. Most of these fibres have been tested and found to lose their strength when subjected to alternate “wetting and drying” environment.

In view of low strength and lack of durability, natural fibres are not in wide use for reinforcements but are preferred for erosion control due to their environment friendliness and biodegradability. However, some natural fibres like coir are strong and durable. They can be made sustainable with proper treatment for reinforcement for reinforcement function in cohesion less soils and also as filter fabric in cohesive soils.

Natural fibres have poor resistance to alkaline environment. Almost all natural fibres get damaged and lose their strength in 24 hours when given 0.1N solution of sodium hydroxide (Rehsi , 1988) . The only exception to this is coir. Coir fibres are even resistant to biodegradation over long period of time. It has been shown that breaking strengths of coir fibre after 15 years of storage in a hanger comes down from 176 MPa to 160 MPa and elongation from 29% to 21%. It shows that coir becomes slightky brittle with time but best among all natural fibres.

1.5.6 Direction of Placement

Fibres can be oriented or randomly mixed in soil. In oriented category, the inclusions are placed within the soil at specific positions and direction where as in random category, inclusions, are mixed with soil and placed within the probable shear zone. The concept of randomly reinforced soil is comparatively new in the geotechnical field. French ministry of public works uses Texsol as RDFS. In the field placing the fibres at some orientation is a tedious job. In reinforced soil the added material (the Geo synthetic sheet, etc) is layered at specific direction and position, which may keep the soil weaken in some other direction. Whereas in ply soil, the isotropy in strength is maintained.

Random reinforcement have been provided to different type of soils in form of mesh elements, discrete fibres continuous yarn / filament (Texsol) metallic power , waste tire – chips , waste plastic strips , etc by various investigators.

1.5.7 Factors Affecting the Strength Characteristics of Engineering Properties of RDFS

The factors on which the strength characteristics and other engineering properties of RFDS depend:

(i) Type of soil it includes soil gradation expressed in terms of mean grain size (D50) and uniformity coefficient (Cu).

(ii) Type of Fibre: Monofilament or fibrillated

(iii) Denier of Fibre: It is the weight (in gm) of 9000 m long fibre.

(iv) Fibre length

(v) Aspect ratio: It is defined as the ratio of the length of fibre to its diameter

(vi) Fibre soil surface friction.

1.6 APPLICATIONS

When designing civil engineering structures, the function to be performed have to be analyzed first, after those suitable materials and products can be selected. When geosynthetics are provided, the soil structure requires a strong, relatively stiff and preferably water permeable material. Table 1.3 gives functional applications of geosynthetics.

Table 1.3 Geosynthetics Applications Summary Table

Application	Primary Function	Products
Sub grade Stabilization	Separation/Reinforcement/Filtration	Geotextiles/Geogrid
Railroad Track Bed Stabilization	Drainage /Separation Filtration	Geotextiles/Geogrid
Sedimentation Control Silt	Sediment Retention	Geotextile
Fence	Filtration/separation	
Asphalt overlay	Stress Reliving layer/ Waterproofing	Geogrid/ Geotextiles

Asphalt overlay	Stress Reliving layer/ Waterproofing	Geogrid/ Geotextiles
Soil reinforcement /Embankments/Steep slope/Vertical walls	Reinforcement	Geotextiles/Geogrid
Erosion control filter	Filtration Separation	Geogrid/ Geotextiles
Geomembrane protection	Protection/cushion	Geomembrane
Subsurface drainage	Filtration/Fluid transmission	Prefabricated drainage composites
Surfacial erosion control	Turf reinforcement	Erosion control mats

1.7 POND ASH/FLY ASH

Pond ash is the by-product of thermal power plants, which is considered as a waste material and its disposal is a major problem from an environmental point of view and also it requires a lot of disposal areas. Actually, there are three types of ash produced by thermal power plants, viz. (1) Fly ash, (2) bottom ash, and (3) pond ash. Pond ash is collected by mechanical or electrostatic precipitators from the flue gases of power plant; whereas, bottom ash is collected from the bottom of the boilers. Then these two types of ash, mixed together, are transported in the form of slurry and stored in the lagoons, the deposit is called pond ash. Besides this steel, copper and aluminium plants also contribute a substantial amount of pond ash. Table 1.4 gives the detail of the industries producing pond ash.

Table 1.4 List of Industries Generating Pond ash/Fly ash

(A) Thermal power plants

Name of the Industry	**Name of the State Situated**	**Name of the Industry**
Kothagendem	Andhra Pradesh	Nellore
Ramagundam	Andhra Pradesh	Vijaywada

Bongaigaon	Assam	Lakwa
Narup		Chandrapura
Barauni	Jharkhand	Bokaro
Chandradurg	Bihar	Muzzafarpur
Patratu		
Indraprasta	Delhi	Rajghat
Badarpur		
Utraw	Gujarat	Gandhinagar
Sabarmati		Utkai
Wanakoi		
Singrauli	Uttar Pradesh	Mirjapur
Rihand		Panki
Paricha		Anapara
Obra		RPC
Hardoganj		Tanda
Ferojgandhi		
Korba	Madhya Pradesh	Satpura
Amarkantak		Vindhyachal
Gurunanak Dev		Ropar
Kota		
Raichur	Karnataka	
Ennore	Tamilnadu	Tuticorin
Mettur		Neyveli

Trombay	Maharastra	Nasik
Ballarshah		Paras
Chola		Bhusawal
Chandanpur		Koradi
Parli		Tata Elec. Co.
Talcher	Orissa	
Durgapur	West Bengal	Bundel
Santadir		Lolaghat
Farakka		DPL
C.E.S.C		Titalagarh
New Cossipore		Mulajore

(B) Steel Industry

Name of the Industry	**Name of the State Situated**
Bhillai Steel	Madhya Pradesh
Durgapur Steel	West Bengal
Rourkela Steel	Odisha
Bokaro Steel	Jharkhand
HSCO	Burnapur,(W.B)
Salem Steel	Tamil Nadu
Vijay Nagar	Karnataka
Visakhapatnam Steel	Andhra Pradesh
TISCO	Jamshedpur,(Jharkhand)

(C) Aluminium Industry

Name of the Industry	**Name of the State Situated**
BALCO	Korba, (M.P)
NALCO	Odisha

(D) Copper Industry

Name of the Industry	**Name of the State Situated**
Chandmari Copper Project	Rajasthan
Khetri Copper Project	Rajasthan
Dariba Copper Project	Rajasthan
Indian Copper Complex	Bihar
Rakha Copper Project	Bihar
Malanjkhand Copper Project	M.P

1.7.1 Factors affecting properties of pond ash

Meyer (1976) and Despande (1982) represent that the chemical and physical composition of a pond ash is a function of several variables.

(1) Coal source

(2) Degree of coal pulverization

(3) Deign of boiler unit

(4) Loading and firing condition

(5) Handling and storage methods.

Thus, it is not surprising that a high degree of variability can occur in pond ash not only between power plants but single power plants. A change in any of the above factors can result in detectable changes in the pond ash produced. The chemical composition of some of the Indian pond ash is given in Table 1.5.

Table 1.5 Chemical Composition of some of the Indian Pond ash

Thermal Plant	SiO3	Al2O3	Fe2O3	CaO	MgO	SO3	LOI	TiO2
Ukkai	52.44	28.12	6.18	3.48	5.44	-	3.88	-
Tuticorn	53.44	22.72	4.48	7.25	3.33	1.34	1.5	-
Bokaro	56.50	25.30	4.10	1.30	1.60	-	18-26	0.5
Delhi	60.10	18.60	6.40	6.30	3.60	-	18-26	-
Hardua	60.78	23.63	6.48	15.59	1.54	-	18-26	-
Korba	58.30	24.64	4.40	5.40	3.90	-	18-26	1.0
Obra	56.15	28.87	8.13	2.29	1.45	1.37	18-26	-
Durgapur	50.65	19.65	18.80	2.20	1.49	-	18-26	-
Satpur	59.70	25.69	7.31	2.0	2.89	1.02	18-26	-
Talcher	47-57	18.31	18.69	0.67	0.28	Trace	1.26	-
Rourkela	45-51	20.25	7.95	2.0-3.0	1.0-1.5	-	18-26	-
Nellore	60.18	18.44	16.28	2.08	1.28	0.58	1.05	-
Neyveli	45-59	23.33	0.6-4.0	5-16	1.5-5	2.50	1-2	0.5-1
Panki	53.44	22.72	6.56	3.22	4.48	-	4.21	-
Chandrapur	56.70	23.80	4.0	2.10	1.40	-	7.4-11.4	-
Kothagudam	66.74	23.20	6.58	2.71	0.77	0.05	0.30	-

Bandel	50-95	24.25	9.95	2.59	3.7	2.91	7.1	-
Panipat	60.64	15.70	2.36	0.80	0.25	-	18.86	-
Paras	55.30	27.81	5.09	3.4	3.08	1.20	3.85	-
Kanpur	49.20	22.00	7.50	2.84	0.98	0.24	15.81	-

1.7.2 Environmental Impact of Pond ash

Some of the current methods of ash disposal can have adverse impacts on the environment, including: land use diversion and resettlement; water resources allocation and pollution; air pollution; and human health. In particular:

- The construction of large ash disposal areas results in resettlement issues, and loss of agricultural production, grazing land and habitat, as well as other land use impacts from diversion of large areas of land to waste disposal. The current practice in some power plants is to use large ash ponds, sometimes in excess of 7000 acres, which usually involves resettlement issues. Since land holdings are typically small in size, a large ash pond development can cause hardships through loss of land-based subsistence and livelihood for literally thousands of people.
- The design of the ash disposal areas themselves is frequently inefficient in terms of economy of land areas usage. There is no uniformity in ash pond engineering practice in India. Some plants are accumulating ash in shallow ponds by diking off natural low lands, resulting in inefficient usage of land areas for accumulation of high-volume waste. In these instances, large areas are inundated and taken out of service for other uses; but the depth of inundation over much of the areas is shallow, and the proportion of land areas usage to disposal storage volume is high. Some power generation organizations are piling up the ash to elevations of

20-30 meters by using the ash itself as pond embankment material, or a combination of earthwork and ash for elevated storage of ash; this method results in a greater storage volume over a smaller area, and therefore a more efficient usage of the area devoted to waste disposal. The ash generated in the power plant is typically mixed with water to form slurry which is pumped to an ash pond and is allowed to settle. Some ash ponds are being operated as one unit. This makes management of ash distribution, water coverage, ash slurry water recycling and minimization of water losses almost impossible.

- The disposal of ash may pollute water resources, including the contamination of groundwater from leachate and the contamination of surface water from discharge of ash pond effluent. Ash pond effluent may be used as a source of irrigation water or potable supply by locals. Leakage in ash slurry pipelines is exploited for irrigation and potable supply, since local water resources are scarce, and distribution systems almost non-existent. Direct consumption of ash-pond effluent can result in the uptake of heavy metals and other toxins. Indirect consumption of ash-pond effluent contaminations can result from the ingestion of food crops that have been irrigated with ash-slurry effluent; and the consumption of livelistock that has consumed water or irrigated crops contaminated by slurry. Often the ash-pond effluent does not meet Indian standards for total suspended solids (TSS) due to poor management of the ash-pond for settling. The release of ash-contaminated (high TSS) water, or slurry contaminated with high total dissolved solids, can result in contamination of the food chain with heavy metals and other toxins, presents as contaminants in the effluents.
- There may be air pollution from fugitive dust, when ash deposits dry without water or vegetation cover. Typically, most of the area of large ash ponds or ash dikes are not covered

by water or wetted. The ash dries up and is an excellent source for fugitive dust emissions. In some instances, reclamation of the dried areas has mitigated fugitive dust emissions. Most areas where the ash ponds are located already have high ambient air concentrations of respirable particulates. High levels of respirable particulars are associated with upper increased incidence of respiratory disease. Fugitive emissions from poorly managed ash disposal areas can contribute to increased local concentrations of respirable particulates, and adversely impact human health.

- Operation of once through slurry disposal systems puts additional strain on scarce fresh water resources. The slurry water could be recycled to avoid water resources pollution and conserve water. Unfortunately, this is not often implemented. Only recently, some State Pollution Control Boards have become aware of water quality and conservation issues and are demanding recycling of ash slurry water in the annual Consent Orders issued to the power plants within their jurisdiction.
- Reclamation of the ash disposal area is often forestalled by engineering and operational practice, extending the time the land use is devoted to non-productive waste disposal. Some ash ponds are being operated as one unit. Operation as one large settling pond means that reclamation will start, if at all, only at the end of the lifetime of the power plant, which is at least 25-30 years. The eventual reclamation has to be performed over a large area. Management of a large area associated with resettlement and rehabilitation (R & R) requires special attention. The use of reclaimed areas for production of food crops and livestock has the potential to introduce bio-accumulative contaminants into the food chain. Various non-food production reclamation techniques have been tried with success, including wood and silkworm production. The choice of reclamation techniques and subsequent use of the

reclaimed areas has the potential to offset the hardships of land ousters and project affected people.

- Earth dam failures present a safety and pollution hazard. Loss of life could occur from catastrophic failure of the dam. In addition, any release of ash from such a failure would impact local aquatic resources, thereby potentially contaminating and eliminating habitat. Poor maintenance of earth dams can be observed, with many earth dams in a state of progressive failure, and little observation for monitoring of conditions of earth dam structures.

1.7.3 Issues for the Millennium

It is estimated that by the end of tenth plan period (March 2007) an additional 124,00MW of power generating capacity expansion will be required in India to meet the rising energy demand. India shall continue to depend on coal as the prime source of energy. Consequently issues for the solid waste management for coal based thermal power plants shall continue to be an area of priority since environmental issues shall hold greater importance in the 21st century.

Keeping in view, India’s development problems like increasing population, scarce natural resources specially land, increasing urbanization and energy requirements, it is only but natural that power generation sector can’t function in isolation. Pond ash is a resource material which should be utilized. The past 5 years have witnessed a significant growth in the technological level with respect to pond ash disposal & utilization in the country and in the next millennium pond ash in itself is going to emerge as a major industry.

1.7.4 Use of pond ash

Pond ash/Fly ash can is used for multifarious applications. Some of the application areas are the following:

- In Land fill and dyke rising.
- In Structural fill for reclaiming low areas.
- Manufacture of Portland cement
- Lime – Flyash Soil Stabilizing in Pavement and Sub-base
- In Soil Conditioning
- Manufacture of Bricks
- Part replacement in mortar and concrete.
- Stowing materials for mines.

CHAPTER 2
LITERATURE REVIEW

LITERATURE REVIEW

2.1 INTRODUCTION

Pond ash is a waste product of coal combination in thermal power plants. It has posses problem for the safe disposal and causes economic loss to the power plants. Thus, the utilization of pond ash in large scale geotechnical constructions as a replacement to conventional earth material needs special attention. The inherent strength of pond ash can be improved by reinforcing.

Reinforced earth is a composite material, which is a combination of soil and reinforcement, suitably placed to withstand the developed tensile stresses and also it improves the resistance of the soil in the direction of the greatest stress. The essential features of reinforced earth are the friction between the earth and reinforcement, by means of friction the soil transfer to the reinforcement the forces built in the earth mass. The reinforcement thus develops tension when the earth mass is subjected to shear stresses along the reinforcement.

2.2 LITERATURE ON REINFORCED SOIL

Andersland and Khattak (1979) have studied on the RDFS using the soil kaolinite with Φ =20°, LL=47.8%, PL= 20.3% and G= 2.7 cellulose fiber (f_l=1.6mm, dia=0.02mm, fibre content 16 and 40%). For this test the triaxial test was conducted. The test result indicates that the addition of fibre @ 16% increases the peak stress by 43% when pure kaolinite was consolidated at 1.16 times higher confining pressure than the composite. Φr obtained by C- U triaxial test at fc of 16% is 80.40°.

Gray and Ohashi (1983) have investigated on RFDS, they reinforced the dry sand (Dr= 20% and 100 %,) with reed, polypropylene and copper fiber. Their direct shear test result shows that the shear strength soon reaches a limiting level in all type of fiber.

McGown, Andrawes and Hytiris (1985) have reinforced the Mid Ross sand (C_u=5, D_{50}=0.5 mm) with polypropylene fiber (with mesh elements of 50mm×50mm, opening size 6.7 mm×7.1mm and f_c= 0.09 to 0.24%). The Drained triaxial and model footing tests results shows the deviator stress developed at all strains , even at very small strains increased with using the mesh and also peak stresses in the sand – mesh mixture occurred at slightly.

Gray and Al-Refeai (1986) have studied on Muskegon pure sand (D_{50}= 0.41mm,C_u= 1.5,Φ=39^0 (D_r=86%) and Φ=32^0(D_r=21%) reinforced with three types of fibre (Reed,d=1.25mm, Reed,d=1.75mm and glass fibres, d=0.30mm,f1= 13,25,38mm geotextiles:Geolon400, Geolon200, Typar 3601,Typar 3401 and fiber glass 196). For this work triaxial compression test were done to compare the stress-strain response of sand reinforced with continuous and they investigated the amount of reinforcement, confining stress, inclusion modulus and surface friction. The result shows at very low strain (<1%) fabric inclusion loss the compressive stiffness. The strength increase with fibre content up to a fibre content of 2% by weight and roughly proportional to fibre aspect ratio.

Setty and Rao (1987) have investigated on Lateritic soil with G=16%, S=60% M=21% and C=1% Φ=390 at optimum moisture content of 16%, LL=33%, PI=7.3% and reinforced with polypropylene fibre (dia 0.5mm, fibre content of 0, 1, 2, 3, 4, 5). Triaxial test, CBR and tensile test were done, each at optimum moisture content. The result shows that using of fibres increases cohesion and slightly decreases Φ, CBR value improved by 2.2 times only up to 2% fibre content and also improves dry strength. Cohesion improved to 5.7 times at fibre content of 3%but Φ decreases to 0.78times.

Lindh and Eriksson (1990) have reinforced the sand (C_u= 3.5 and D_{50}=0.5mm) with monofilament polypropylene fibre at fibre content of 0.25% and 0.5%. They were conducted a field experiment by placing a reinforced sand layer on the existing road surface for field experiment. Their result shows that no rutting is taken place.

Maher and Gray (1990) have reinforced the coarse sand of nine types at C_u=1 to 4, D_{50}=0.09 to 0.65mm , 10% moisture content with rubber (dia=1.1mm,a_r=20, f_l=22mm),glass(dia=0.3mm,a_r=60,08,125,f_l=45mm),reed fiber(dia=0.3,ar=20,f=18,24,38mm) Their Drain triaxial tests shows that low modulus fibres(rubber) contribute little to strength despite higher interface friction. Faliure surface are plain and oriented at (45+Φ/2).An increase in particle sphericity is higher in critical confining pressure and lower fibre contribution. Higher aspect ratio resulted lower confining pressure and increasing shear strength.

Fatani et al. (1991) have studied on the silt sand with C_u=5 D_{50}=0.9, c=10kN/m^2, Φ=47^0 and reinforced with monofilament fiber of 70mm long, oriented (to the shear plane at 450 to 900) and random, number varies from 5to 32. The Drained direct test was done at modified proctor dry density γ = 20.8kN/m^3 and optimum moisture content 8.9%, orientation of fiber is perpendicular to shear plane. The test result shows that fiber placed parallel to slip plane of direct shear box caused reduction in shear strength. In randomly place, only 10-20% fibres cross the shear plane is actually impart the strength.

Al-Refeai (1991) have reinforced the two type of sand (with C_u= 1.67, D_{50}=0.18, Φ=350 and Cu=0.94, 50=0.78, Φ=40.5) with polypropylene mesh (dia=0.4, f_l=25&50, f_c=0.5-2%), polypropylene pulp and glass fibres (dia=0.1, f_l=2-100, fc=0.5-2%). The triaxial test was conducted at Dr=50% and 60% at 6% moisture content. The result shows that fine sand gives better than medium sand and rounded sand give higher strength than angular sand optimum value of polypropylene fibre content is 2%, afterwards strength decreases and aspect ratio is 75. Short fibres require greater confining stress to prevent pullout.

Bauer and Fatani (1991) have studied on silt sand (with C_u=5, D_{50}=0.9,c=10kN/m^2, $\Phi=47^0$ at optimum moisture content) reinforced with steel fibre (rigid, dia=3mm,fl=40mm,,random) an copper(flexible , dia= 0.8mm ,fl=70mm,5,6 and 32 fibres aligned) They investigated the direct shear test and pull out test at modified proctor density test of 2.08t/m3 and moisture content of 8.9%, $\Phi=37^0$ and δ=23°. The result shows that the residual strength of composite is 200% to 300% higher than unreinforced soil and well graded soil give highest anchorage capacity.

Maher and Ho (1994) reinforced the Kaoloine (with LL=45, PL=15) with monofilament polypropylene (dia=0.32,f_l=2.5 to 20mm, f_c=1 to 5%) and glass fibres (dia= 0.05mm,f_l=6 to 25mm ,f_c=1 to5%). The unconfined compression test, splitting tension and three point bending were done and for this test the polypropylene fibre is added from 1% to 5% on soil. The addition of polypropylene fibres improves the unconfined compressive strength linearly (from 1.2 times to 1.4) Increasing the fibre length from 5mm to 20 mm, decreases q_u from 1.4 to1.2 times.

Michalowski and Zaho(1996) have reinforced the dry sand (with C_u=1.52 and D_{50}=0.89) with polyamide monofilament and steel fibres (dia0.3,0.4mm aspect ratio 85 and 180 , fibre length and content 25 and 0.5% respectively) . The triaxial result shows that the addition of steel fibres increases the peak stress by 20% and presence of fibres inhibited the sample dilation and made sample stiff, before reaching the failure.

Ranjan et al (1996) have studied on the various type of soil like sand , medium sand, fine sand, silty sand ,silt (with C_u= 2.3 to 2.4, c=1.8 to31 and Φ=32to34) reinforced with polypropylene monofilament (dia = 0.3 mm a_r=50to 100 f_c=0 to 4%) and coir (monofilament dia= 0.2 mm ,a_r =50 to 125, f_c= 0to 4%) and bhabar (dia= 0.2 mm , a_r= 50to 125 , f_c= 0 to 4%). The result of Triaxial test (CU) on partially saturated sample of RDFS shows greater ductility, no loss of post peak strength and increase in stiffness. Due to tensile stress in fibres confining pressure is greater than critical confining pressure, decreases with increase in aspect ratio and soil fibre surface friction.

Charan (1996) has studied on silt sand to coarse sand (D_{50}= 0.06-0.5mm) reinforced with polypropylene (dia=0.3 mm, a_r=50to 125, f_l=15 to 37, f_c= 0.5 to 3%) and natural fibres coir and bhabar (a_r = 50 to 100 f_l= 15 to 37 mm, f_c=0.5 to 3%). In this triaxial and CBR test were done to check the failure of composite. Triaxial result shows that confining pressure less than critical confining i.e1.2, strength of composite is un-affected by improving the density of composite. The CBR value is improved by 2 times at fibre content at 1.5%.

Wasti and Butun (1996) have reinforced the sand soil (with C_u=3.995, C_c=1.132, D_{60} = 0.819 mm c= 6.98 ,Φ=47.8°) with polypropylene (30×50 mm small, 50×100mm big size and opening 10×10 mm 50mm long fibre by cutting mesh. They were conducted Laboratory model test on a strip footing 50mm (width) x 250 mm (length) supported by sand and randomly distributed polypropylene fibre and mesh element. Results indicate that reinforcement of sand caused an increase in the ultimate bearing capacity values and settlement at ultimate load. The big mesh size is superior to other and increases in ultimate bearing capacity.

Ranjan et al. (1999) have reinforced the clay (with LL= 58%, PL= 37%) and sand (γ= 18, Φ=34^0&cohesion 10.5kPa) with monofilament polypropylene fibre (dia=0.3mm and δ=21^0). For the triaxial test moist sample of clay was drilled to and was filled with mixture of sand and fibre.

The triaxial result shows peak of normal stress at 10-20% of axial strain in unreinforced soil, but reinforced soil do not shows any peak. Shear strength increases linearly with increasing the amount of fibres up to 2% and residual strength is higher than unreinforced soil.

Santoni et al. (2001) have studied on six types of non plastic cohesion less soils reinforced with monofilament polypropylene fibre (denier = 4,15,20 f_l=13 to 51 mm ,f_c =0 to 1% 0). The unconfined compressive strength of RDFS was done at base moisture content 2.6% and saturation 14%. They obtained the optimum fibre content is 0.8% and fibre content <0.6% caused strain softening , >0.85 causes strain hardening and q_u improves slightly by increasing aspects ratio.

Gosavi et al.(2004) have studied on the black cotton soil (Ll=38%,PL=14%,c=41kN/m^2,Φ= 14^0 and CBR=4.9%) reinforced with fibre glass (d= 0.1mm, aspect ratio =250 and 500mm, fc=1,2,3%) mixed randomly. They investigated the direct shear test and CBR test and the result shows OMC and cohesion(c) increase & MDD and angle of internal friction (Φ) decrease upto 2% of f_c than trend were reversed on further increase of fibre content. CBR value is decrease with increase of f_c and safe bearing increase by 33.58% and 29.67% due to addition of glass fiber with aspect ratio 50 and 500 respectively.

Kumar, Wallia and Bajaj (2007) have reinforced the black cotton soil with properties (Gs= 2.72%, LL=68% PL= 49.65% optimum moisture content = 29.4% maximum dry density =1.32 gm/cc) with polyester synthetic. They investigated of unconfined compression of fly ash, lime and randomly oriented fibres on the geotechnical characteristics of expansive soil. The result shows that unconfined compressive strength increases with increase in fibre content, which shows that fibre are more efficient when soil is subjected to tension rather than compression.

Chandra et al. (2008) have reinforced the three types of soil clay, silt and silty sand with polypropylene fibre of 0.3mm diameter. The fibres were cut into pieces of 15, 25, and 30mm in length and aspect ratio of 50, 80 and 100 respectively and with percentage of0.75, 1.5, 2.25 and 3 by dry weight of soil. The static triaxial test of unreinforced and reinforced soil was conducted. Their result shows that the uniaxial compressive strength is 3.824, 4.836 and 9.712 MPa respectively.

2.3 LITERATURE ON REINFORCED POND ASH

Digioa (1972) says that with drainage, the ash can be effectively and economically utilized as a fill material to construct stable embankment for land reclamation on which structure can be safely founded.

Leonards (1972) reported that untreated pulverised coal ash with no cementing quantities was used successfully as a material for structural fill. Although, the ash was inherently variable, it could be compacted satisfactorily, if the moisture content was maintained below the optimum obtained from standard laboratory tests and if the percentage of fines (passing the No.200 sieve) was below 60%.

Kumar et al. (1999) gives the results of laboratory investigations conducted on silty sand and pond ash specimens reinforced with randomly distributed polyester fibres. The test results reveal that the inclusion of fibres in soils increases the peak compressive strength, CBR value, peak friction angle, and ductility of the specimens. It is concluded that the optimum fibre content for both silty sand and pond ash is approximately 0.3 to 0.4% of the dry unit weight.

Pandey et al. (2002) attempted to devise the ways for the use of this mixed ash for manufacturing mixed ash clay bricks successfully. The bricks thus made are superior in structural and aesthetic qualities and portents huge saving in the manufacturing costs with better consumer response.

Bera et al. (2007) presented the study on compaction characteristics of pond ash. Three different types of pond ash have been used in this study. The effects of different compaction controlling parameters, viz. compaction energy, moisture content, layer thickness, mold area, tank size, and specific gravity on dry density of pond ash are highlighted herein. The maximum dry density and optimum moisture content of pond ash vary within the range of 8.40–12.25 kN/m3 and 29–46%, respectively. In the present investigation, the degree of saturation at optimum moisture content of pond ash has been found to vary within the range of 63–89%. An empirical model has been developed to estimate dry density of pond ash, using multiple regression analyses, in terms of compaction energy, moisture content, and specific gravity. Linear empirical models have also been developed to estimate maximum dry density and optimum moisture content in the field at any compaction energy. These empirical models may be helpful for the practicing engineers in the field for planning the field compaction control and for preliminary estimation of maximum dry density and optimum moisture content of pond ash.

Bera et al. (2007) implemented on the effective utilization of pond ash, as foundation medium. A series of laboratory model tests have been carried out using square, rectangular and strip footings on pond ash. The effects of dry density, degree of saturation of pond ash, size and shape of footing on ultimate bearing capacity of shallow foundations are presented in this paper. Local shear failure of a square footing on pond ash at 37% moisture content (optimum moisture content) is observed up to the values of dry density 11.20 kN/m3 and general shear failure takes place at the values of dry density 11.48 kN/m3 and 11.70 kN/m3. Effects of degree of saturation on ultimate bearing capacity were studied. Experimental results show that degree of saturation significantly affects the ultimate bearing capacity of strip footing. The effect of footing length to width ratio (L/B), on increase in ultimate bearing capacity of pond ash, is insignificant for $L/B \geq 10$ in case of rectangular footings. The effects of size of footing on ultimate bearing capacity for all shapes of footings viz., square, rectangular and strip footings are highlighted.

Chand et al. (2007) presented the effects of lime stabilization on the strength and durability aspects of a class F pond ash, with a lime constituent as low as 1.12%, are reported. Lime contents of 10 and 14% were used, and the samples were cured at ambient temperature of around 30°C for curing periods of 28, 45, 90, and 180 days. Samples were subjected to unconfined compression tests as well as tests that are usually applied to rocks such as point load strength tests, rebound hammer tests, and slake durability tests. Unconfined compressive strength (UCS) values of 4.8 and 5.8 MPa and slake durability indices of 98 and 99% were achieved after 180 days of curing for samples stabilized with 10 and 14% lime, respectively. Good correlations, that are particularly suitable for stabilized materials of low density and low strength, have been derived for strength parameters obtained from UCS tests, point load strength tests, and Schmidt rebound hammer tests, and also between UCS and slake durability index.

Bera et al. (2009) have studied the shear strength response of reinforced pond ash, a series of unconsolidated undrained (UU) triaxial test has been conducted on both unreinforced and reinforced pond ash. In the present investigation the effects of confining pressure (σ3), number of geotextile layers (N), and types of geotextiles on shear strength response of pond ash are studied. The results demonstrate that normal stress at failure (σ_{1f}) increases with increase in confining pressure. The rate of increase of normal stress at failure (σ_{1f}) is maximum for three layers of reinforcement, while the corresponding percentage increase in r1f is around (103%), when the number of geotextile layers increases from two layers to three layers of reinforcement.

With increase in confining pressure the increment in normal stress at failure, Δr increases and attains a peak value at a certain confining pressure (threshold value) after that Δr becomes more or less constant. The threshold value of confining pressure depends on N, dry unit weight (γ_d) of pond ash, type of geotextile, and also type of pond ash.

Ghosh et al. (2010) presents the laboratory test results of a Class F pond ash alone and stabilized with varying percentages of lime (4, 6, and 10%) and PG (0.5, and 1.0), to study the suitability of stabilized pond ash for road base and sub-base construction. Standard and modified Proctor compaction tests have been conducted to reveal the compaction characteristics of the stabilized pond ash. Bearing ratio tests have been conducted on specimens, compacted at maximum dry density and optimum moisture content obtained from standard Proctor compaction tests, cured for 7, 28, and 45 days. Both un-soaked and soaked bearing ratio tests have been conducted. This paper highlights the influence of lime content, PG content, and curing period on the bearing ratio of stabilized pond ash. The empirical model has been developed to estimate the bearing ratio for the stabilized mixes through multiple regression analysis. Linear empirical relationship has been presented herein to estimate soaked bearing ratio from un-soaked bearing ratio of stabilized pond ash. The experimental results indicate that pond ash-lime-PG mixes have potential for applications as road base and sub base materials.

Jakka et al. (2010) studied carried on the strength and other geotechnical characteristics of pond ash samples, collected from inflow and outflow points of two ash ponds in India, are presented. Strength characteristics were investigated using consolidated drained (CD) and undrained (CU) triaxial tests with pore water pressure measurements, conducted on loose and compacted specimens of pond ash samples under different confining pressures. Ash samples from inflow point exhibited behaviour similar to sandy soils in many respects. They exhibited higher strengths than reference material (Yamuna sand), though their specific gravity and compacted maximum dry densities are significantly lower than sands. Ash samples from outflow point exhibited significant differences in their properties and values, compared to samples from inflow point. Shear strength of the ash samples from outflow point are observed to be low, particularly in loose state where static liquefaction is observed.

2.4 SCOPE OF PRESENT STUDY

Thus, through appraisal of the literature review it is observed that several attempts have already been made by researchers to understand the mechanism of randomly oriented discrete inclusions incorporated into soil improve its load-deformation behavior by interacting with soil particles mechanically through surface friction and also by interlocking. However, in the present study an attempt has been made to improve the geo-engineering properties of compacted pond ash by polyester fibre (recron-3s). Hence, the experimental programme undertaken investigates:

- ❖ The effect of compaction energy on shear parameters and unconfined compressive strength of unreinforced pond ash specimens.
- ❖ The effect of degree of saturation on shear parameters, unconfined compressive strength and CBR value of unreinforced pond ash specimens.
- ❖ The effect of fibre content & aspect ratio on shear parameters, unconfined compressive strength and CBR value of reinforced pond ash specimens.

CHAPTER-3
EXPERIMENTAL WORK AND METHODOLOGY

EXPERIMENTAL WORK AND METHODOLOGY

3.1 INTRODUCTION

Safe and economic disposal of pond ash is the main concern of coal based thermal power plants. Large scale utilization of pond ash in geotechnical constructions will reduce the problems faced by the thermal power plants for its disposal. In this connection assessment of the behaviour of structures constructed using pond ash is required for stability and safe functioning of structures. Even through adequate substitute for full scale field tests are not available; tests at laboratory scale have the advantage of allowing a close control of many of the variable encountered in practice. The trends and behaviour pattern observed in the laboratory tests can be used in understanding the performance of the structures in the field and may be used in formulating mathematical relationship to predict the behaviour of field structures. In the present work the behaviour of randomly reinforced compacted pond ash has been evaluated through a series unconfined compression test, Shear strength parameters and CBR tests. Details of material used, sample preparation and testing procedure adopted has been outlined in this chapter.

3.2 MATERIAL USED

3.2.1 POND ASH

3.2.1.1 Source of Pond ash

Pond ash used in this study was collected from the thermal power plant of CPP-NSPCL, Rourkela Steel Plant. The samples were dried at the temperature of 105-110 degrees. The ash sample was screened through 2mm sieve to separate out the foreign and vegetative matters. Then the pond ash samples were stored in airtight container for subsequent use.

3.2.1.2 Physical Properties of Pond ash

The physical properties of the pond ash sample passing through 2mm sieve were determined and are presented in Tables 3.1.

Table 3.1 Physical Properties of Pond ash

Physical parameters	**Values**	**Physical parameters**	**Values**
Colour	Light grey	Shape	Rounded/sub-rounded
Silt &clay (%)	26	Uniformity coefficient, C_u	2.15
Fine sand (%)	73.4	Coefficient of curvature, C_c	1.25
Medium sand (%)	5.6	Specific Gravity, G	2.37
Coarse sand (%)	0	Plasticity Index	Non- plastic

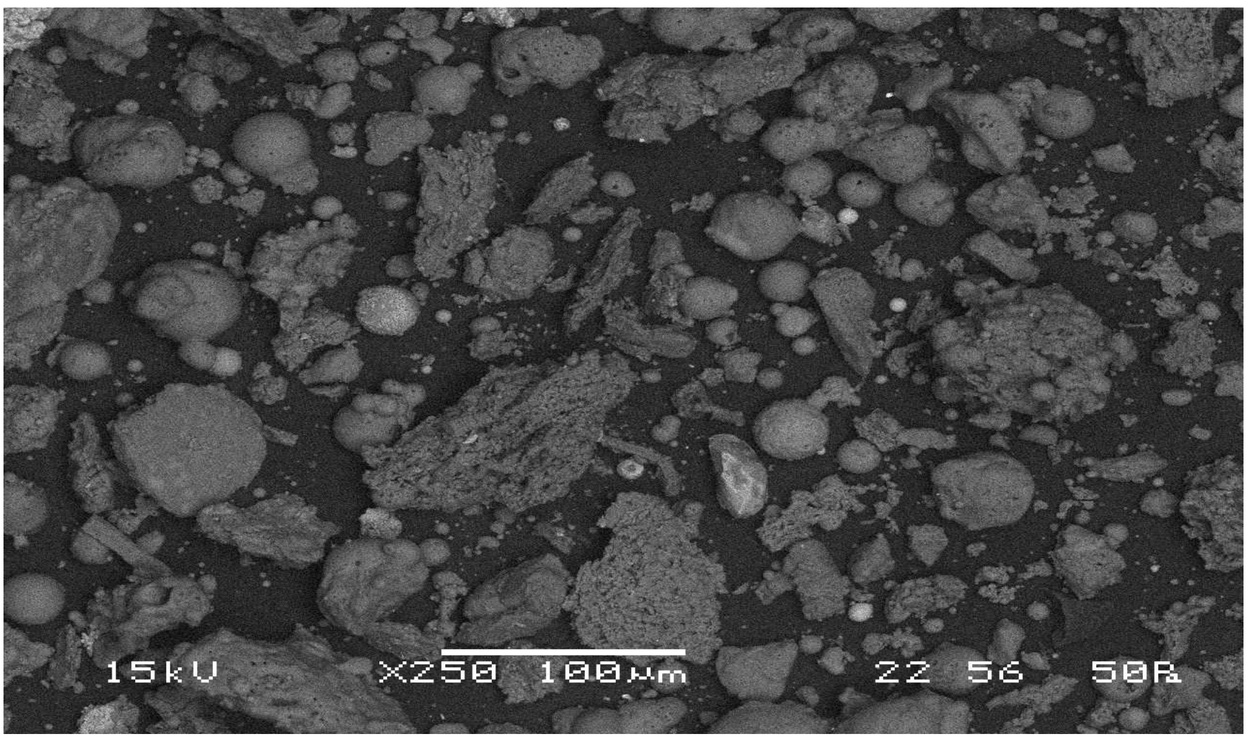

Fig.3.1 Scanning Electron Micrograph (SEM) of Pond ash

3.2.1.3 Chemical composition of Pond ash

The chemical compositions of the pond ash sample passing through 2mm sieve were determined and are presented in Tables 3.2.

Table 3.2 Chemical Composition of Pond ash

Constituents	%age	Constituents	%age	Constituents	%age
SiO_2	57.80	P_2O_5	0.19	Na_2	0.16
Al_2O_3	25.10	SO_3	0.28	TiO_2	1.65
Fe_2O_3	8.83	K_2O	0.82	Carbon	4.10
MgO	0.84	CaO	1.14	Volatile Matter	0.14

3.2.2 GEO-FIBRE

3.2.2.1 Source of Geo-fibre

Geo-fibre used for the test was bought from the market (shop) of 125gm packet having different sizes 6mm and 12mm. The fiber used for reinforced pond ash specimens was a polyester fiber (Recron-3s). These fibers were made from polymerization of pure teraphthalic acid and Mono Ethylene Glycol using a catalyst. These fibers were found to be widely used in concrete technology. Fig. 3.1 shows a view of fibres used in this study. Scanning Electron Micrograph (SEM) of fiber is given in Fig.3.2 which has a special triangular cross-section and equivalent diameter of fiber was about 32 µm– 55 µm. This special triangular cross-section is good for anchoring and interaction with pond ash.

3.2.2.2 Physical Properties of Geo-fibre

The physical properties of fibers, as supplied by the manufacturer are shown in Table 3.3.

Table 3.3 Summaries of Fibre Properties (as supplied by the manufacturer)

Property	Values	Property	Values
Colour	White	Specific Gravity	1.334
Cut length	6mm,12mm	Equivalent diameter (μm)	32-55
Denier (d)	1.5	Water absorption (%)	85.22
Tensile Strength (MPa)	600	Acid resistance	Excellent
Melting Point (°C)	>250	Alkali resistance	Good

Note: Denier is a unit of measure for the linear mass density of fibres. It is defined as the mass in grams per 9000 m.

Fig.3.2 Views of fibres (Recron-3s)

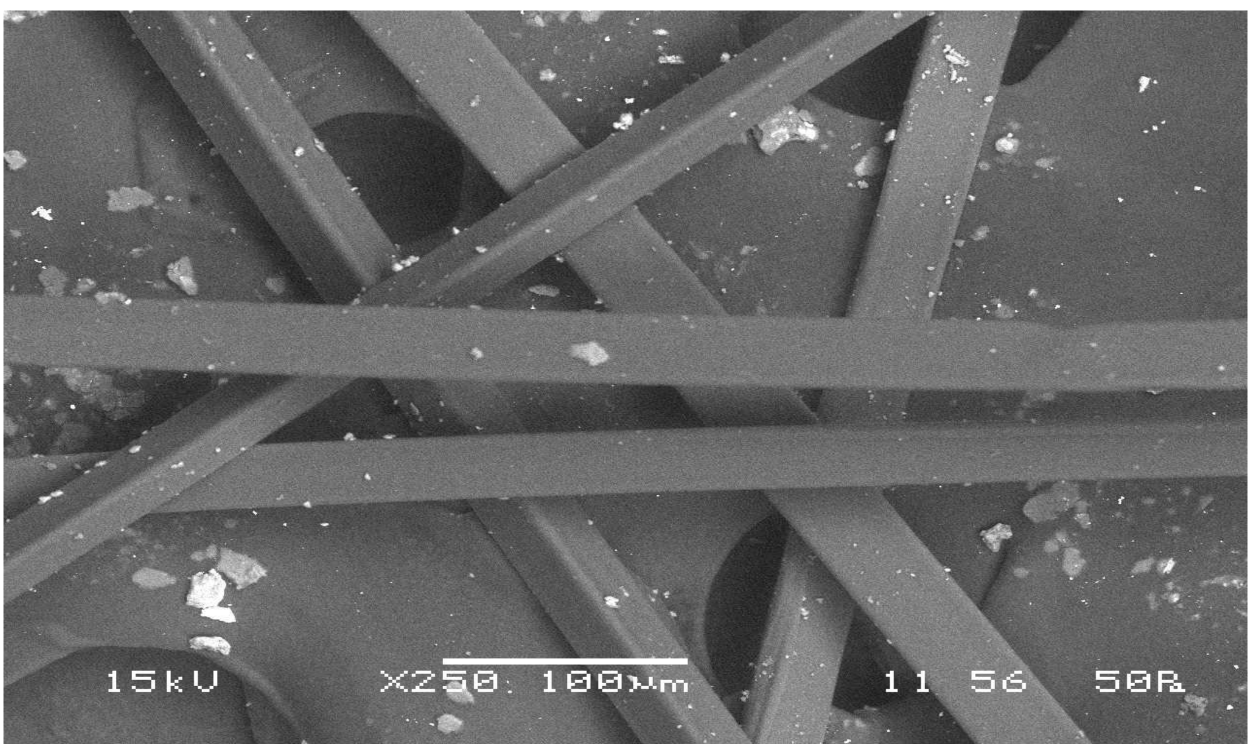

Fig.3.3 Scanning Electron Micrograph (SEM) of fiber (Recron-3s)

3.2.2.3 Role of RECRON-3s

• **Controls Cracking:**

RECRON 3s prevents the shrinkage cracks developed during curing making the structure/plaster/component inherently stronger. Further when the loads imposed on concrete approach that for failure, cracks will propagate, sometimes rapidly. Addition of RECRON 3s in concrete and plaster prevents/arrests cracking caused by volume change (expansion & contraction).

• Reduces water permeability:

A cement structure free from such micro cracks prevents water or moisture from entering and migrating throughout the concrete. This in turn helps prevent the corrosion of steel used for primary reinforcement in the structure. This in turn improves longevity of the structure.

• Reduces Rebound In Concrete - Brings Direct Saving &Gain:

RECRON 3s fibers reduce rebound "splattering" of concrete and shotcrete. The raw material wastage reduces & results in direct saving in terms of raw material. More importantly it saves a great deal of labour employed for the job, which could be completed earlier.

• Increases Flexibility:

The modulus of elasticity of RECRON 3s is high with respect to the modulus of elasticity of the concrete or mortar binder. The RECRON 3s fibers help increase flexural strength.

• Safe and Easy To Use:

RECRON 3s fibers are environmental friendly and non hazardous. They easily disperse and separate in the mix.

3.2.2.4 Primary Applications of RECRON-3s:

• Plain concrete & Wall plastering

• Footings, foundations, walls and tanks

• Pipes, burial vaults, pre-stressed beams etc.

• For improving the properties of soil by increasing its strength.

• Roads & pavements

• Bridges and dams

3.3 DETERMINATION OF INDEX PROPERTIES

3.3.1 Determination of Specific Gravity

The specific gravity of pond ash was determined according to IS: 2720 (Part-III, section-1) 1980. The specific gravity of pond ash was found to be 2.37.

3.3.2 Determination of Grain Size Distribution

For determination of grain size distribution, the pond ash was passed through test sieve having an opening size 75µ. Sieve analysis was conducted for coarser particles as per IS: 2720 part (IV), 1975 and hydrometer analysis was conducted for finer particles as per IS: 2720 part (IV). The percentage of pond ash passing through 75µ sieve was found to be 33.7%. Hence the particle size of pond ash ranges from fine sand to silt size. Coefficient of uniformity (C_u) and coefficient of curvature (C_c) for pond ash was found to be 2.15 & 1.25 respectively, indicating uniform gradation of samples. The grain size distribution curve of pond ash is presented in Fig. 4.1.

3.4 DETERMINATION OF ENGINEERING PROPERTIES

3.4.1 Moisture Content Dry Density Relationship

The moisture content, dry density relationships were found by using compaction tests as per IS: 2720 (Part 7) 1980. For this test, pond ash was mixed with required amount of water and the wet sample was compacted in proctor mould either in three or five equal layers using standard proctor rammer of 2.6 kg or modified proctor rammer of 4.5 kg. The moisture content of the compacted mixture was determined as per IS: 2720 (Part 2) 1973. From the dry density and moisture content relationship, optimum moisture content (OMC) and maximum dry density (MDD) were determined. Similar compaction tests were conducted with varying compactive energy and the corresponding OMC and MDD were determined. This was done to study the effect of compactive energy on OMC and MDD. The compactive energies used in this test programme were 357, 595, 1493, 2674, 2790 and 3488 kJ/m^3 of compacted volume. The test results are presented in Table 3.4.

Table 3.4 Compaction characteristics of unreinforced pond ash with different compactive effort

Sl. No.	E (kJ/m^3)	OMC (%)	MDD (kN/m^3)
1	357	38.82	10.90
2	595	35.92	11.08
3	1493	31.38	11.60
4	2674	28.30	12.40
5	2790	28.72	12.61
6	3488	28.09	12.70

3.4.2 Determination of Shear Parameters

The shear parameters on unreinforced pond ash specimens compacted to their corresponding MDD at OMC with compactive effort varying as 357, 595, 1493, 2674, 2790 and3488kJ/m^3 were determined as per IS: 2720 (Part 13) 1986[13]. Test specimens were prepared corresponding to their MDD at OMC. These specimens were of size 60mm×60mm×25mm deep and sheared at a rate of 1.25 mm/minute. The shear strength parameters of the compacted specimens were determined from normal stress versus shear stress plots and it is given in Table

3.5. To study the effect of degree of saturation on the shear parameters, samples were prepared at a standard and modified dry density but the moisture contents were varied as desired is given in Table 3.6. Also, to study the effect of fibre content on the shear parameters, compacted reinforced pond ash samples were prepared at a standard and modified dry density but the fibre content were varied as 0.2, 0.3, 0.4, 0.5, 0.75, 1.0% are presented in Table 3.7 and similarly, the normalized shear parameters are tabulated in Table 3.8.

Table 3.5 Shear parameters of unreinforced pond ash (at different compactive efforts)

Sl. No.	E (kJ/m^3)	OMC (%)	MDD (kN/m^3)	c_u (kN/m^2)	Φ (°)
1	357	38.82	10.90	0.799	37.48
2	595	35.92	11.08	1.440	38.30
3	1493	31.38	11.60	2.753	39.20
4	2674	28.30	12.40	6.638	40.55
5	2790	28.72	12.61	7.373	41.46
6	3488	28.09	12.70	8.363	44.47

Table 3.6 Shear parameters of unreinforced pond ash (at fixed standard and modified proctor density varying with water content)

Sl. No.	Standar Proctor Density ($11.08kN/m^2$)			Modified Proctor Density ($12.40kN/m^2$)		
	M.C (%)	c_u (kN/m^2)	Φ (°)	M.C (%)	c_u (kN/m^2)	Φ (°)
1	43.09	4.7	31.2	33.96	5.8	31.8
2	39.50	7.4	31.7	31.13	10.0	32
3	35.91,OMC	10.6	31.7	28.03,OMC	11.6	32.8
4	32.32	7.4	32.8	25.47	9.4	34.4
5	30.52	6.3	33.9	24.05	8.0	34.6

Table 3.7 Shear parameters of reinforced pond ash (at standard and modified proctor density varying with fibre content)

Sl. No.	Fibre Content (%)	Standard Proctor Density (11.08kN/m^2)				Modified Proctor Density (12.40kN/m^2)			
		6mm fibre		12mm fibre		6mm fibre		12mm fibre	
		c_u (kN/m^2)	Φ (°)	c_u (kN/m^2)	Φ (°)	c_u (kN/m^2)	Φ (°)	c_u (kN/m^2)	Φ (°)
1	0%	1.44	38.3	1.4403	38.3	6.64	40.6	6.64	40.6
2	0.2%	4.97	39.4	5.23	41.3	8.56	44.2	12.82	49.2
3	0.3%	5.76	40.2	6.21	42.4	9.08	44.6	14.82	50.2
4	0.4%	7.16	40.5	8.14	43.6	11.50	45.3	16.90	51.5
5	0.5%	9.22	41.9	9.64	44.3	12.21	45.5	17.54	52.3
6	0.75%	10.25	41.4	14.21	45.4	15.45	46.2	19.55	53.3
7	1.0%	13.08	42.9	19.89	51	16.85	47.3	20.72	54.2

Table 3.8 Normalized Shear parameters of reinforced pond ash (at standard and modified proctor density varying with fibre content)

Sl. No.	Fibre Content (%)	Standard Proctor Density (11.08kN/m^2)				Modified Proctor Density (12.40kN/m^2)			
		6mm fibre		12mm fibre		6mm fibre		12mm fibre	
		c_u	Φ	c_u	Φ	c_u	Φ	c_u	Φ
1	0%	1	1	1	1	1	1	1	1
2	0.2%	3.45	1.02	3.63	1.09	1.28	1.08	1.93	1.20
3	0.3%	4	1.05	4.31	1.10	1.36	1.09	2.23	1.22
4	0.4%	4.97	1.07	5.65	1.15	1.73	1.10	2.54	1.26
5	0.5%	6.40	1.08	6.69	1.16	1.83	1.11	2.64	1.27
6	0.75%	7.12	1.09	9.86	1.19	2.32	1.13	2.94	1.30
7	1.0%	9.08	1.10	13.81	1.34	2.53	1.160	3.12	1.32

3.4.3 Determination of Unconfined Compressive Strength

Unconfined compressive strength tests on unreinforced pond ash specimens compacted to their corresponding MDD at OMC with compactive effort varying as 357, 595, 1493, 2674, 2790 and3488kJ/m^3 were performed according to IS: 2720 (Part 10) 1991. For this test cylindrical specimens were prepared corresponding to their MDD at OMC in the metallic split mould with dimension 50mm (dia.) × 100mm (high). These specimens were tested in a compression testing machine with strain rate of 1.25% per minute till failure of the sample. The unconfined compressive strengths of specimens were determined from stress versus strain curves plots and it is given in Table 3.9. To study the effect of degree of saturation on the unconfined compressive strength, samples were prepared at a standard and modified dry density but the moisture contents were varied as desired is given in Table 3.10. Also, to study the effect of fibre content on the unconfined compressive strength, compacted reinforced pond ash samples were prepared at a standard and modified dry density but the fibre content were varied as 0.2, 0.3, 0.4, 0.5, 0.75, 1.0% are presented in Table 3.11 and similarly, the normalized unconfined compressive strength are tabulated in Table 3.12.

Table 3.9 Unconfined compressive strength of compacted unreinforced pond ash (at different compactive efforts)

Sl. No.	E (kJ/m^3)	OMC (%)	MDD (kN/m^3)	UCS (kN/m^2)
1	357	38.82	10.90	1.20
2	595	35.92	11.08	2.80
3	1493	31.38	11.60	6.60
4	2674	28.30	12.40	14.80
5	2790	28.72	12.61	15.90
6	3488	28.09	12.70	17.00

Table 3.10 Unconfined compressive strength of unreinforced pond ash (at fixed standard and modified proctor density varying with water content)

Sl. No.	Standard Proctor Density ($11.08kN/m^2$)			Modified Proctor Density ($12.40kN/m^2$)		
	M.C (%)	Failure Strain (%)	UCS (kN/m^2)	M.C (%)	Failure Strain (%)	UCS (kN/m^2)
1	35.92	1.5	2.82	36.79	2	6.17
2	32.33	1.5	3.384	33.96	2	8.414
3	28.73	1.5	4.512	31.13	2	9.536
4	25.14	1.6	6.204	28.3	1.8	14.023
5	21.55	1.6	7.332	25.47	1.85	14.8
6	17.96	1.4	9.024	22.64	1.75	20
7	14.37	1.4	11.845	19.81	1.8	23
8	10.78	1.1	10.253	16.98	1.6	27.062
9	7.19	0.5	6.837	14.15	1.55	28.753
10	-		-	8.49	1.25	23.5
11	-		-	5.66	1	18.133

Table 3.11 Unconfined compressive strength of reinforced pond ash (at standard and modified proctor density varying with fibre content)

Sl. No.	Fibre Content (%)	Standard Proctor Density ($11.08kN/m^2$)		Modified Proctor Density ($12.40kN/m^2$)	
		6mm fibre	12mm fibre	6mm fibre	12mm fibre
		UCS (kN/m^2)	UCS (kN/m^2)	UCS (kN/m^2)	UCS (kN/m^2)
1	0%	2.8	2.8	14.55	14.55
2	0.2%	3.2	4.5	15	22
3	0.3%	3.4	5.5	16	23
4	0.4%	3.6	6	17	24
5	0.5%	3.8	6.5	18	26
6	0.75%	4.4	7	19	29
7	1.0%	5.4	7.5	21	35

Table 3.12 Normalized Unconfined compressive strength of reinforced pond ash (at standard and modified proctor density varying with fibre content)

Sl. No.	Fibre Content (%)	Standard Proctor Density ($11.08kN/m^2$)		Modified Proctor Density ($12.40kN/m^2$)	
		6mm fibre	12mm fibre	6mm fibre	12mm fibre
		NUCS	NUCS	NUCS	NUCS
1	0%	1	1	1	1
2	0.2%	1.142	1.607	1.030	1.512
3	0.3%	1.214	1.964	1.099	1.580
4	0.4%	1.285	2.142	1.168	1.649
5	0.5%	1.357	2.321	1.237	1.786
6	0.75%	1.571	2.5	1.305	1.993
7	1.0%	1.928	2.678	1.443	2.405

3.4.4 Determination of California Bearing Ratio

Bearing ratio is one of the vital parameters, used in the evaluation of soil sub grades for both rigid and flexible pavements design. It is also an integral part of several pavement thickness design methods. To assess the suitability of pond ash a series of bearing ratio tests have been carried out unreinforced specimens. The bearing ratio tests are conducted in accordance with IS: 2720-16(1961). For this test cylindrical specimens were prepared corresponding to their MDD at OMC in a rigid metallic cylinder mould with an inside diameter of 150 mm and a height of 175 mm. A mechanical loading machine equipped with a movable base that moves at a uniform rate of 1.2 mm/min and a calibrated proving ring is used to record the load. For this, Static compaction is done by keeping the mould assembly in compression machine and compacted the pond ash by pressing the displacer disc till the level of the disc reaches the top of the mould. Keep the load for some time, and then release. Remove the displacer disc and then put it under testing machine. To study the effect of degree of saturation on the CBR value, samples were prepared at a standard and modified dry density but the moisture contents were varied as desired is given in Table 3.13 and Table 3.14 . Also, to study the effect of fibre content on the bearing resistance, compacted reinforced pond ash samples were prepared at a standard and modified dry density of different size of fibre 6mm and 12mm, but the fibre content were varied as 0.2, 0.3, 0.4, 0.5, 0.75, 1.0% are presented in Table 3.15 to Table 3.18.

Table 3.13 CBR Test result for unreinforced pond ash specimens with variation moisture content at standard proctor density of 11.08 kN/m^3

Sl. No.	Moisture Content (%)	Dry Density (kN/m^3)	Degree of Saturation (%)	CBR value (%) at 2.5 mm penetration	CBR value (%)at 5.0 mm penetration	Normalized CBR Values 2.5mm Penetration	Normalized CBR Values 5.0mm Penetration
1	43.10	11.08	89.57	0.248	0.232	0.124	0.120
2	39.51	11.08	82.06	0.447	0.497	0.224	0.258
3	35.92,OMC	11.08	74.74	1.988	1.922	1.000	1.000
4	28.73	11.08	59.72	2.784	2.552	1.400	1.327
5	25.14	11.08	52.20	3.480	3.115	1.750	1.620
6	21.55	11.08	44.69	3.629	3.314	1.825	1.724
7	17.96	11.08	37.37	3.977	3.579	2.000	1.862
8	14.37	11.08	29.86	4.773	4.176	2.400	2.172
9	10.78	11.08	22.34	5.916	5.237	2.975	2.724
10	07.19	11.08	14.83	6.563	5.866	3.301	3.052
11	03.59	11.08	7.32	7.259	5.402	3.651	2.810
12	00.00	11.08	0	3.231	2.552	1.625	1.327

Table 3.14 CBR Test result for unreinforced pond ash specimens with variation moisture content at modified proctor density of 12.40 kN/m^3

Sl. No.	Moisture Content (%)	Dry Density (kN/m^3)	Degree of Saturation (%)	CBR value (%) at 2.5 mm penetration	CBR value (%)at 5.0 mm penetration	Normalized CBR Values 2.5mm Penetration	Normalized CBR Values 5.0mm Penetration
1	33.96	12.40	88.30	4.226	3.944	0.324	0.331
2	31.13	12.40	80.95	5.718	4.972	0.439	0.417
3	28.30,OMC	12.40	73.61	13.025	11.908	1.000	1.000
4	22.64	12.40	58.72	17.863	15.382	1.371	1.291
5	19.81	12.40	51.38	18.608	15.878	1.428	1.333
6	16.98	12.40	44.04	23.818	18.359	1.828	1.541
7	14.15	12.40	36.70	26.051	20.344	2.000	1.708
8	11.32	12.40	29.36	29.772	24.760	2.285	2.079
9	8.49	12.40	22.02	37.216	29.722	2.857	2.495
10	5.66	12.40	14.68	40.193	33.245	3.085	2.791
11	2.83	12.40	7.34	44.659	34.734	3.428	2.916
12	0	12.40	0	29.772	19.848	2.285	1.666

Table 3.15 Bearing Resistance of reinforced pond ash (at standard proctor density) for 6mm fibre

Strain Levels (%) → / Fibre Content (%) ↓	5	10	15	20	25	30	40	50
0	0.434	0.514	0.594	0.641	0.681	0.741	0.821	0.941
0.2	0.300	0.467	0.621	0.768	0.908	1.035	1.342	1.623
0.3	0.307	0.514	0.681	0.835	1.008	1.202	1.623	2.004
0.4	0.334	0.614	0.794	1.062	1.262	1.523	1.903	2.351
0.5	0.320	0.607	0.828	1.102	1.336	1.636	2.124	2.651
0.75	0.320	0.607	0.868	1.142	1.462	1.750	2.344	2.952
1	0.374	0.701	1.002	1.315	1.67	1.997	2.658	3.413

Table 3.16 Bearing Resistance of reinforced pond ash (at modified proctor density) for 6mm fibre

Fibre Content (%) \ Strain Levels (%)	5	10	15	20	25	30	40	50
0	3.175	3.999	4.060	3.636	4.023	3.284	3.090	3.333
0.2	1.639	2.825	3.492	4.012	4.558	5.172	6.198	7.278
0.3	1.866	3.039	3.799	4.465	5.145	5.865	7.211	8.531
0.4	1.639	3.172	4.158	5.065	5.905	6.731	8.277	9.930
0.5	1.540	3.155	4.249	5.218	6.287	7.206	9.070	10.760
0.75	1.242	3.056	4.348	5.442	6.585	7.703	9.964	12.002
1	1.391	3.379	4.746	5.964	7.330	8.573	11.232	13.344

Table 3.17 Bearing Resistance of reinforced pond ash (at standard proctor density) for 12mm fibre

Fibre Content (%) \ Strain Levels (%)	5	10	15	20	25	30	40	50
0	0.434	0.514	0.594	0.641	0.681	0.781	0.821	0.941
0.2	0.332	0.504	0.664	0.837	0.970	1.142	1.488	1.833
0.3	0.332	0.544	0.757	0.943	1.129	1.328	1.740	2.126
0.4	0.332	0.544	0.770	0.996	1.235	1.488	2.059	2.591
0.5	0.332	0.598	0.863	1.063	1.368	1.661	2.272	2.923
0.75	0.372	0.598	0.890	1.196	1.541	1.926	2.697	3.521
1	0.265	0.571	0.916	1.275	1.687	2.126	3.069	4.093

Table 3.18 Bearing Resistance of reinforced pond ash (at modified proctor density) for 12mm fibre

Fibre Content (%) \ Strain Levels (%)	5	10	15	20	25	30	40	50
0	3.175	3.999	4.060	3.636	4.023	3.284	3.090	3.333
0.2	1.478	2.351	2.836	3.466	3.951	4.605	5.914	7.053
0.3	1.939	3.03	3.636	4.314	4.993	5.623	6.859	8.168
0.4	1.624	2.811	3.636	4.387	5.235	6.156	7.708	8.968
0.5	1.308	2.496	3.393	4.242	5.260	6.302	8.241	9.696
0.75	0.436	2.230	3.514	4.726	6.181	7.272	9.526	11.15
1	0.848	2.933	4.363	5.696	7.078	8.362	10.88	12.53

CHAPTER-4
TEST RESULTS AND DISCUSSION

TEST RESULTS AND DISCUSSION

4.1 INTRODUCTION

Pond ash a by-product of the coal based thermal power plants contains grains of fine sand to silt size. The use of randomly reinforced pond ash in geo-technical constructions requires a proper understanding of the interaction between the pond ash and reinforced material. The stability of pond ash reinforced structure depends upon the strength characteristics of the composite material. A series of conventional laboratory tests such as light and heavy compaction tests, unconfined compressive strength tests, direct shear tests and CBR tests have been carried out on compacted pond ash and with different proportion of recron-3s fibre. Test result are presented and discussed in this chapter.

4.2 INDEX PROPERTIES

4.2.1 Specific Gravity

The specific gravity of pond ash was determined according to IS: 2720 (Part-III, section-1) 1980 and found to be 2.37. The specific gravity of pond ash is found to be lower than that of the conventional earth material. The specific gravity of pond ash depends on the source of coal, degree of pulverization and firing temperature. The presence of foreign materials in the fissures of the coal seams mostly influences the specific gravity of resulting pond ash. Moreover the pond ash is subjected to mixing with other earth materials during its transportation and depositions, which influences its specific gravity. Though the chemical composition of pond ash is very much similar to earth material but as the particles are cenospheres it results in a lower specific gravity.

4.2.2 Grain Size Distribution

The pond ash consists of grains mostly of fine sand to silt size as shown in Fig 4.1. Coefficient of uniformity and coefficient of curvature are found to be 2.15 & 1.25 respectively, indicating uniform gradation of samples. The grain size distribution mostly depends on degree of pulverization of coal and firing temperature in boiler units. The presence of foreign materials in pond ash also influences its grain size distribution. In ash pond the original particles undergoes flocculation and conglomeration resulting in an increase in particle size.

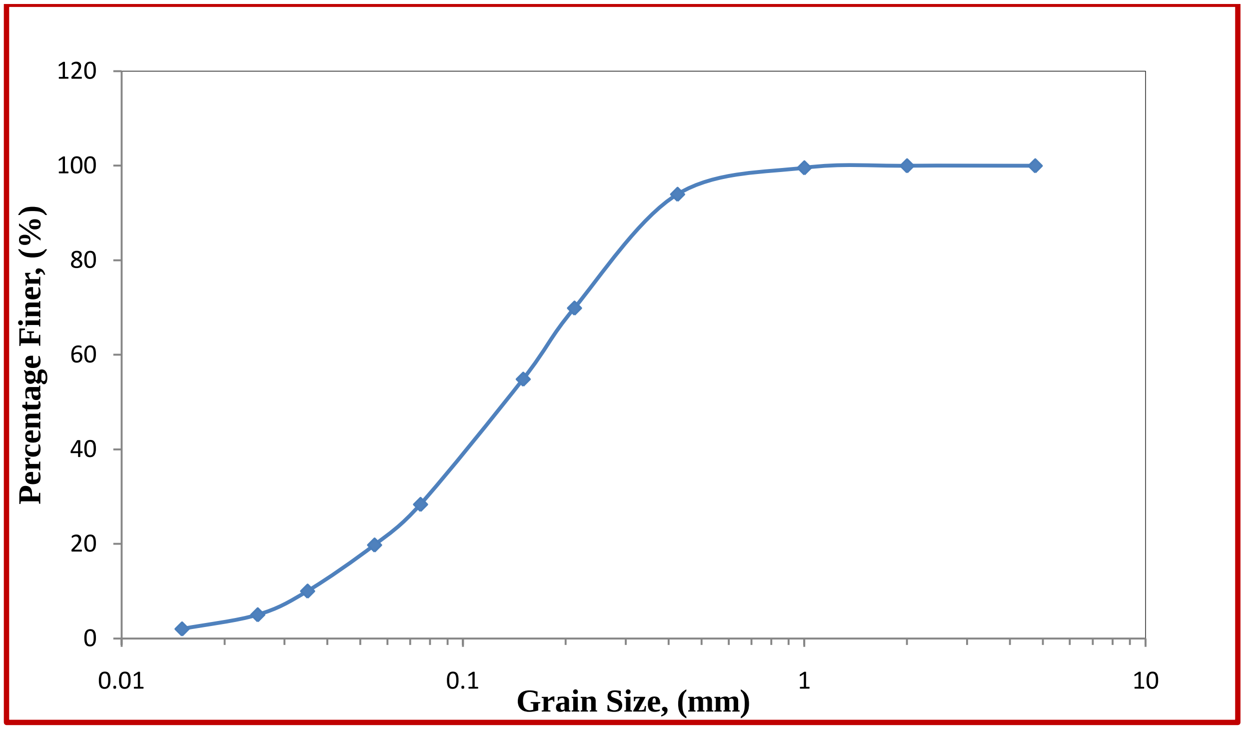

Fig.4.1 Grain size distribution curve of pond ash.

4.3 ENGINEERING PROPERTIES

4.3.1 Compaction Characteristics

The compaction characteristics of pond ash with different compaction energies have been studied by varying the compaction energies as 357, 595, 1493, 2674, 2790 and 3488kJ/m^3 of compacted volume. The OMC and MDD of pond ash samples corresponding to these compactive efforts have been evaluated and presented in Table 3.4. Relationship between dry density and moisture content of pond ash at different compaction energies have been shown in Fig 4.2. It is seen that as the compactive energy increases the MDD increases and the water required to achive this density is reduced. Plot between OMC and compactive energy (Fig.4.3) shows that initially the

OMC decreases rapidly with compactive effort and then the rate of decrease is not that prominent. A continuous increase in the value of MDD is observed with the compactive energy (Fig.4.4). The MDD of specimens is found to change from 10.90 to 12.70kN/m^3 with change in compaction energy from 357 to 3488kJ/m^3 whereas the OMC is found to decrease from 38.82 to 28.09%. This shows that the compacted density of pond ash responds very poorly to the compaction energy. This may be attributed to the rounded shape of particles and uniform gradation of the sample.

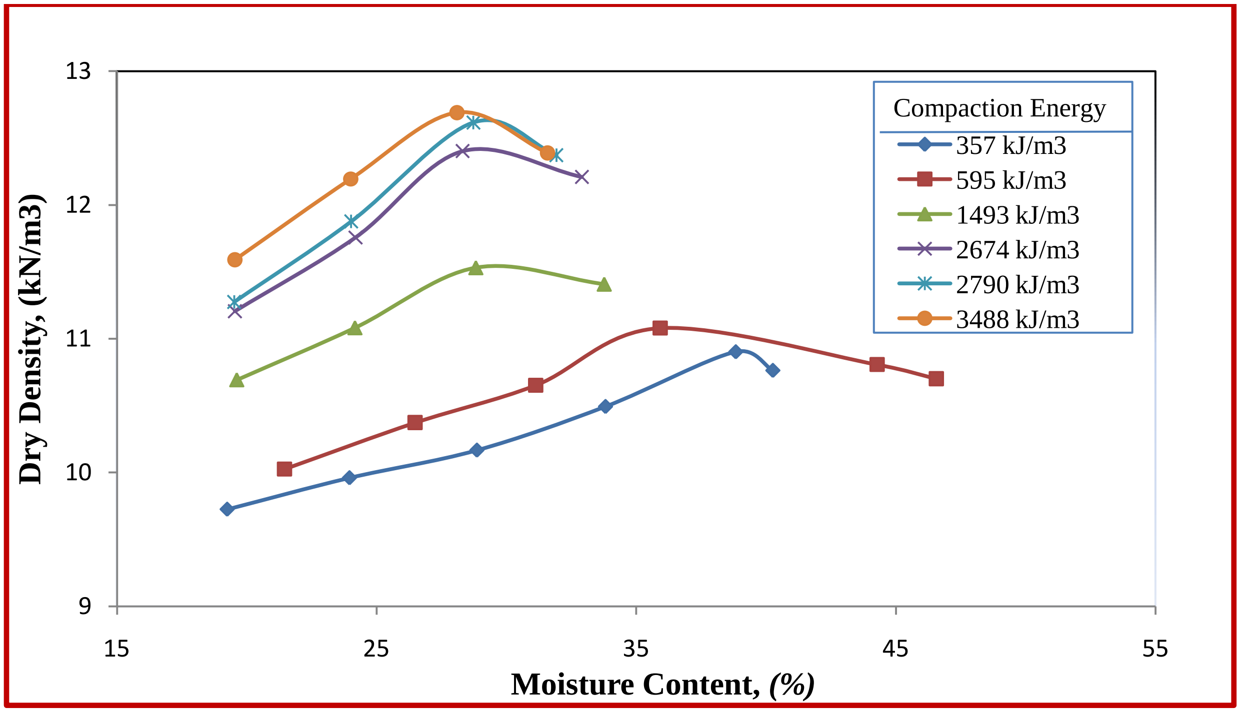

Fig.4.2 Variation of dry density with moisture content at different compaction energy.

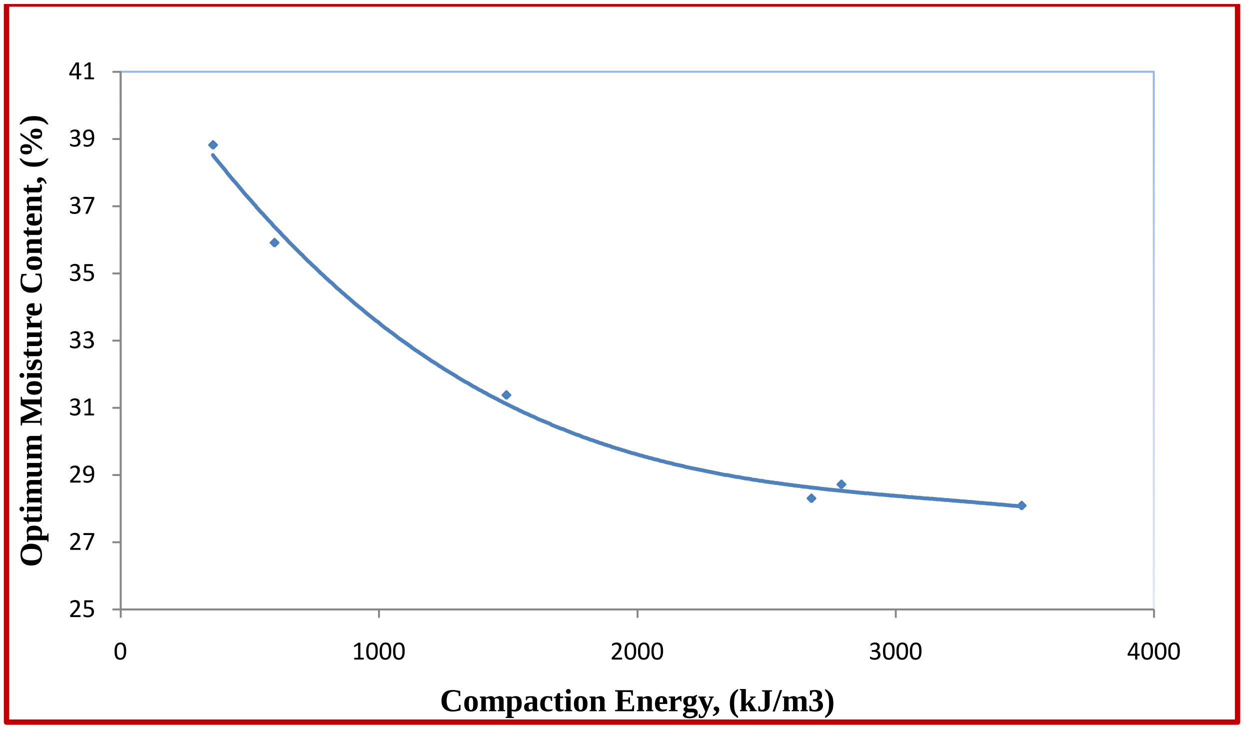

Fig.4.3 Variation of optimum moisture content with compaction energy.

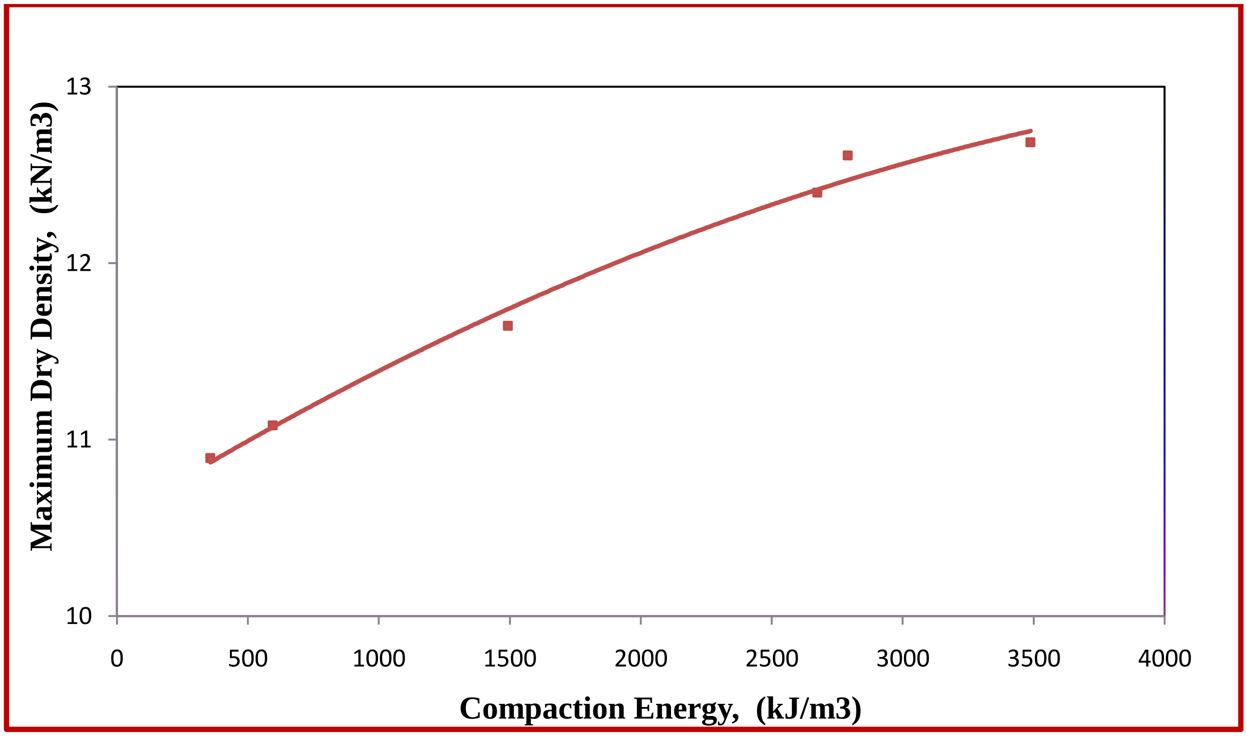

Fig.4.4 Variation of maximum dry density with compaction energy.

4.3.2 Shear Parameters

4.3.2.1 Effect of compaction energy

The shear parameters of the compacted pond ash specimens were determined for specimens compacted to different dry densities and moisture contents. Typical shear stress and normal stress relationship plots of compacted pond ash are presented in Fig.4.5. It is observed that the unit cohesion and the angle of internal friction vary from 0.7988 to 8.363kPa and 37.80 to 44.78 degree with the change in compaction energy from 357 to 3488kJ/m^3. The shear strength parameters of Badarpur and Indraprasta pond ash in loose and dense conditions were reported by Jakka et al. 2010[15, 16]. The values of angle of internal friction of these pond ashes varies from 22.3° to 38.6° with zero effective unit cohesion. This shows that the shear parameters of pond ash is akin to the source as well as degree of compaction moreover the shear strength properties of pond ash is also a function of source of coal, degree of pulverization design and firing temperature of boiler units and degree of flocculation of particles in ash pond. Plot between compaction energy and unit cohesion (Fig.4.6), shows that there exists a nonlinear relation between them. Initially the rate of increase of unit cohesion with compaction energy is low followed by a sharp increase. Similar trend is also observed between the angle of internal friction and compaction energy (Fig.4.7).

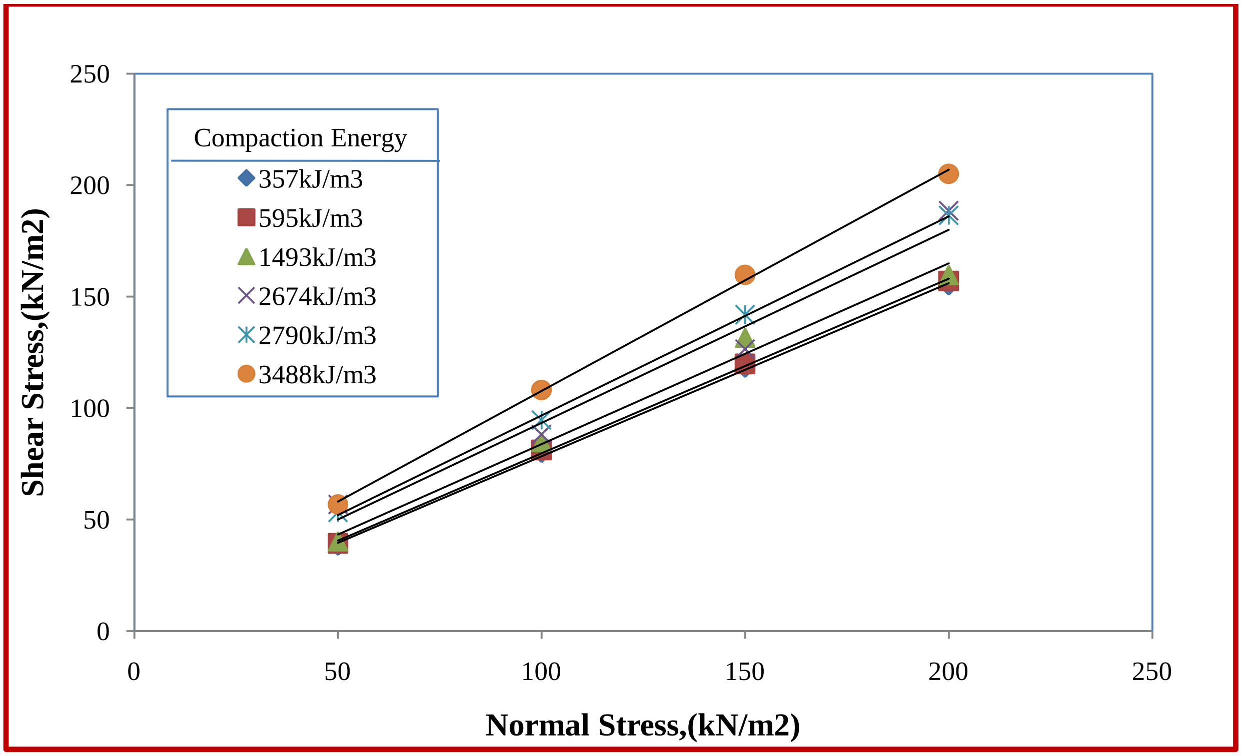

Fig.4.5 Typical Shear Stress versus Normal Stress plots for compacted pond ash.

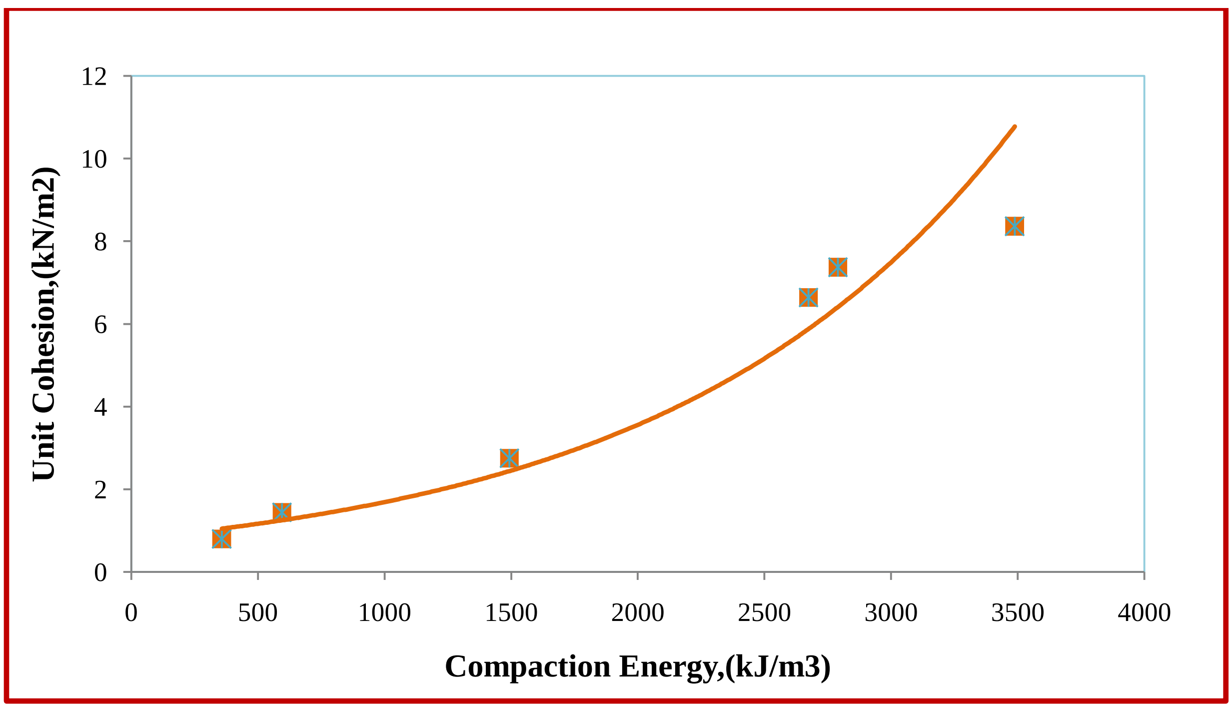

Fig.4.6 Variation of unit cohesion with compaction energy for specimens compacted at OMC & MDD.

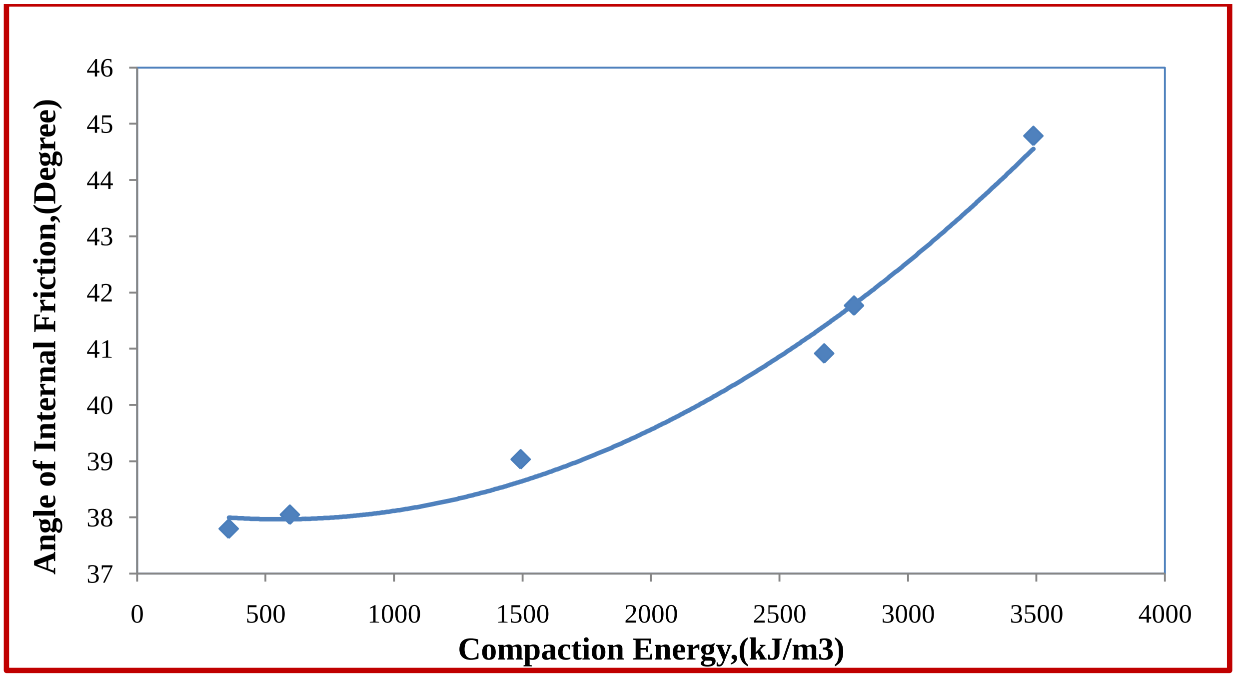

Fig.4.7 Variation of angle of internal friction with compaction energy for specimens compacted at OMC &MDD

4.3.2.2 Effect of degree of saturation

The effect of degree of saturation on shear parameters were studied by varying the moulding moisture content from 30.52 to 43.09% for samples compacted at standard Procter density (11.08kN/m^3) and from 24.05 to 33.96% for samples compacted at modified Procter density (12.40kN/m^3). The variations of normal stress and shear stress for the above mentioned conditions are given in Figs. 4.8 & 4.9 respectively. Plots between unit cohesion and moisture content (Fig.4.10), show that the unit cohesion increases with degree of saturation up to OMC and thereafter, the same decreases. The highest value of unit cohesion occurs at OMC for samples compacted both at standard and modified densities. However, the plot between angle of internal friction and moisture content (Fig.4.11) show that there is a continuous decrease of angle of internal friction value with degree of saturation. Initially there is a sharp decrease which gets stabilized at moisture contents higher than OMC. Pond ash which is non-plastic in nature possess no inter- particular attraction (cohesion), however the compacted samples of specimens posses negligible amount of cohesion (pseudo-cohesion/apparent cohesion) due to surface tension effect. The apparent cohesion of compacted specimens of pond ash becomes zero as the sample becomes completely dry or fully saturated, with the peak apparent cohesion in between. So, in the presence case the maximum unit cohesion is observed at of OMC of the specimens. The angle of internal friction of the compacted pond ash is found to be slightly lower than the conventional earth material of similar gradation. This is obvious because most of the ash particles are rounded/sub-rounded in shape, devoid of any interlocking properties. There is sharp decrease in angle of internal friction value of compacted ash sample with degree of saturation. The added water lubricates the surface of ash particles thus, reducing its angle of internal friction from 33.8° to 31.5°for standard proctor density and 34.8° to 32° for modified proctor density.

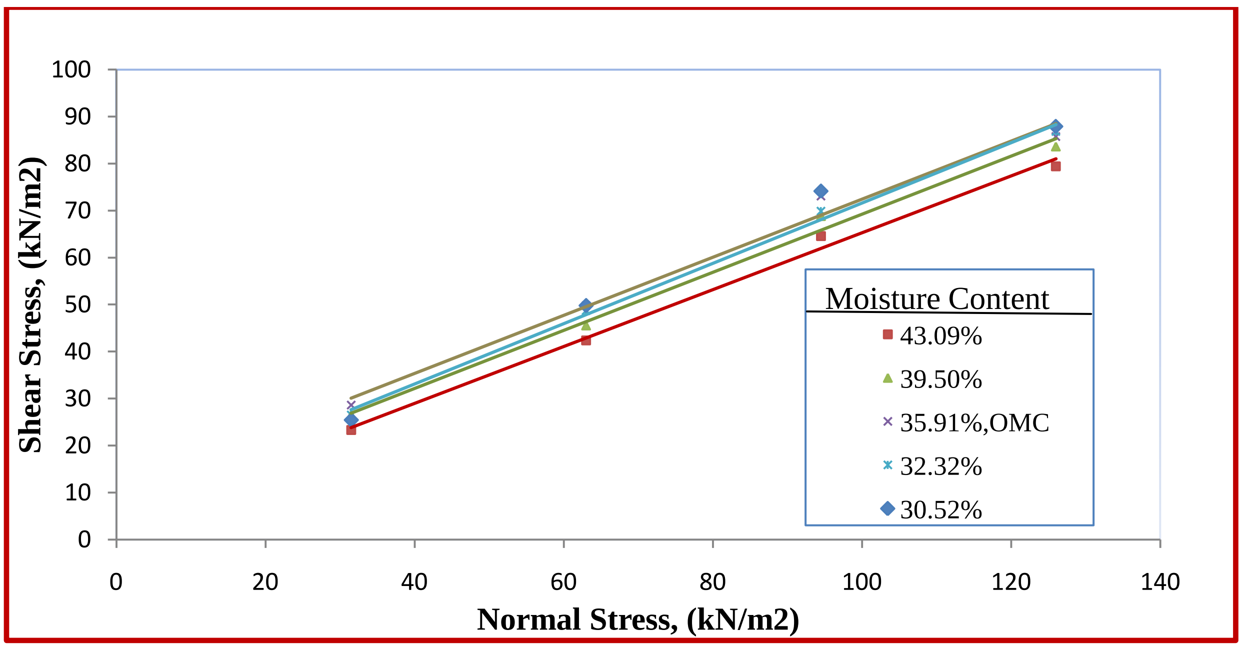

Fig.4.8 Shear Stress versus Normal Stress plots of specimens with moisture content at dry density of 11.08kN/m^3.

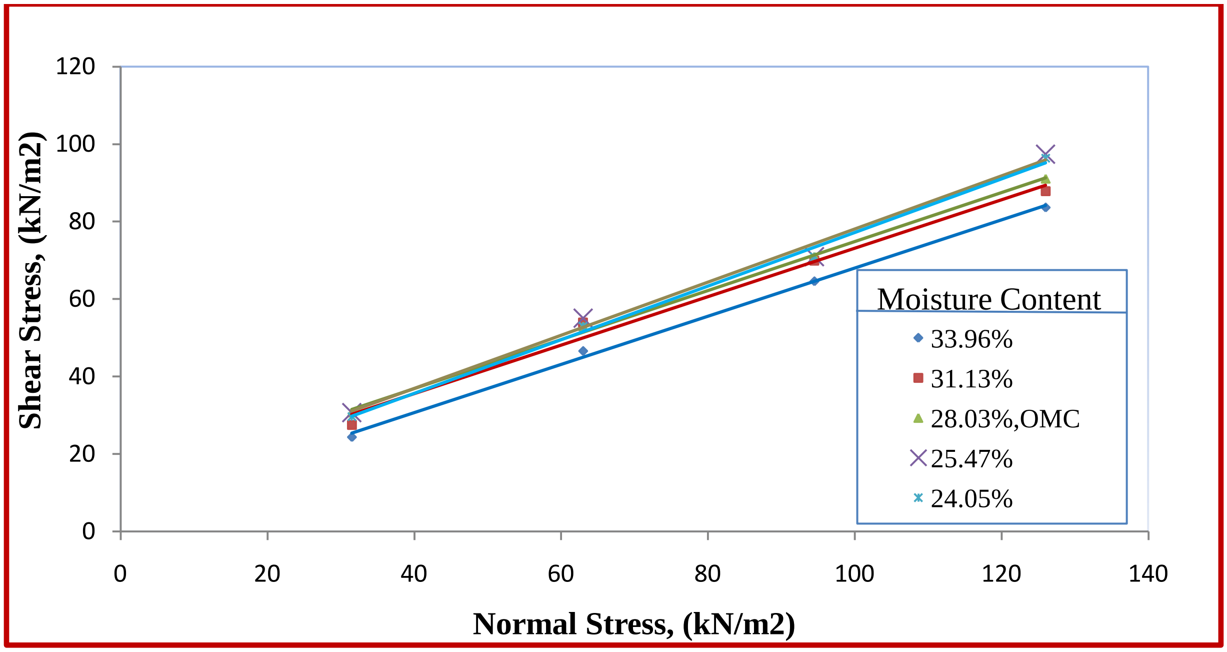

Fig.4.9 Shear Stress versus Normal Stress plots of specimens with moisture content at dry density of 12.4kN/m^3.

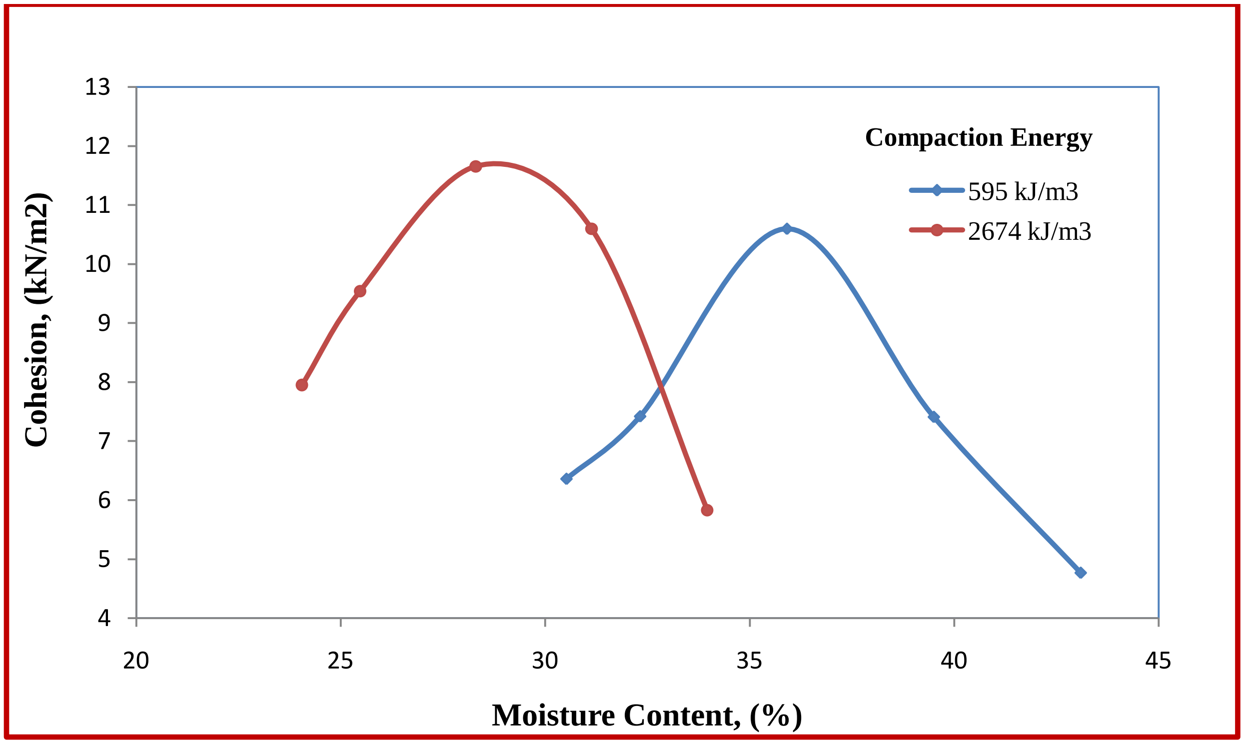

Fig.4.10 Variation of unit cohesion with degree of saturation

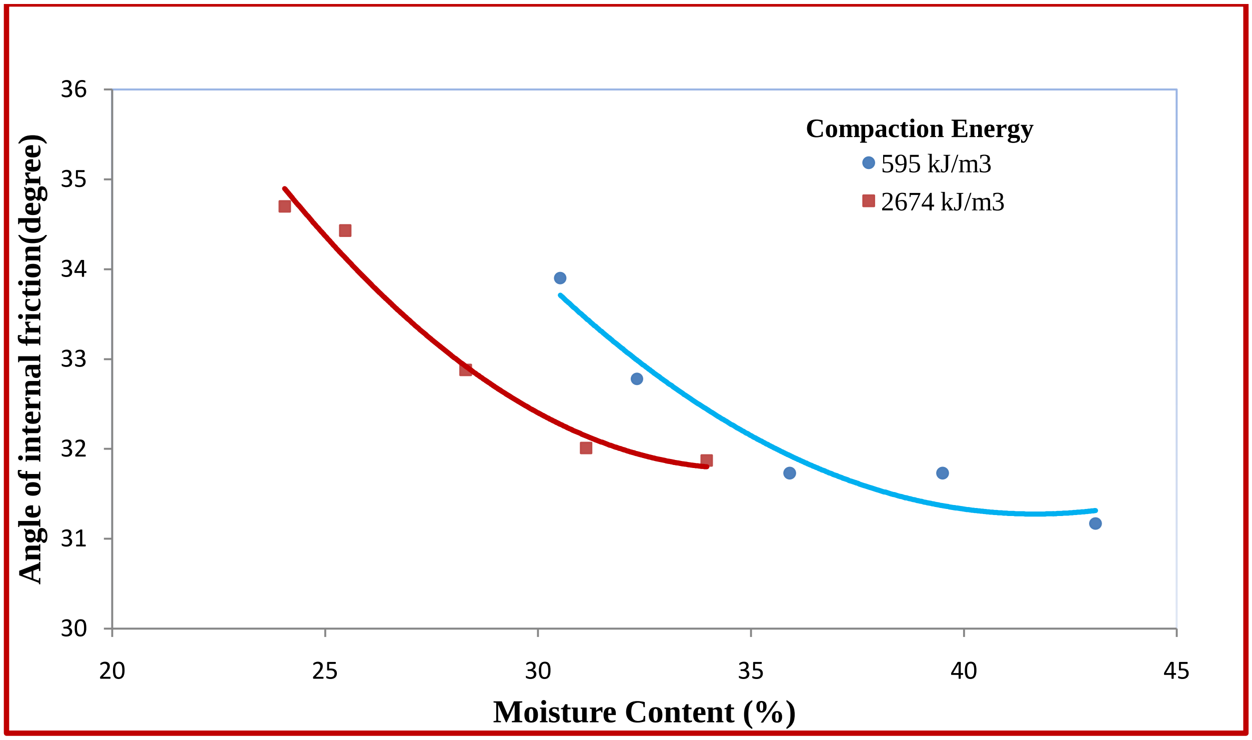

Fig.4.11 Variation of angle of internal friction with degree of saturation.

4.3.2.3 Effect of Fibre content and aspect ratio

The shear parameters of the pond ash specimens reinforced with two different sizes of fibres that is 6mm and 12mm length were determined for specimens compacted to standard and modified proctor density with different percentage of fibre (i.e. 0.2%, 0.3%, 0.4%, 0.5%, 0.75%, and 1.0%). Typical normal stress versus shear stress plots for reinforced (6mm fibre) pond ash at standard proctor density is presented in Fig.4.12. It is observed that the unit cohesion and the angle of internal friction vary from 4.97 to 13.08kPa and 39.0 to 42.1 degree with the change in fibre content from 0.2% to 1.0%. Typical normal stress versus shear stress plots for reinforced (6mm fibre) pond ash at modified proctor density is presented in Fig.4.13. It is observed that the unit cohesion and the angle of internal friction vary from 8.56 to 16.85 kPa and 44.2 to 47.4 degree with the change in fibre content from 0.2% to 1.0%. Similarly, normal stress versus shear stress plots for reinforced (12mm fibre) pond ash at standard proctor density is presented in Fig.4.14. It is observed that the unit cohesion and the angle of internal friction vary from 5.24 to 19.89 kPa and 41.5 to 51.0 degree with the change in %age of fibre from 0.2% to 1.0%. Typical normal stress versus shear stress plots for reinforced (12mm fibre) pond ash at modified proctor density is presented in Fig.4.15. It is observed that the unit cohesion and the angle of internal friction vary from 12.82 to 20.72 kPa and 49.3 to 54.3degree with the change in %age of fibre from 0.2%, to 1.0%. Fig. 4.16 and Fig.4.17 shows the variation of unit cohesion and angle of internal friction with fibre content for reinforced (6mm &12mm fibre) pond ash specimens compacted at standard & modified proctor density. The unit undrained cohesion of reinforced specimens is found to increase with the fibre content. However, the rate of increase of unit undrained cohesion with fibre content is not linear. Initially the rate of increase is high thereafter the increase in unit cohesion is not that prominent. Similar trend is also observed between the angles of internal friction with fibre content. The plots also reveal that the 12mm size fibre is more effective than 6mm size fibres. The fibres modifies the stress condition in the specimens and transfer the tensile strain along the failure plane to the surrounding mass by combined effect of adhesion and friction between the fibre and ash particles. For shorter fibres (6mm) sufficient anchorage to fibre might not be developed leading to pull-out failure and lesser mobilization of fibre capacity. In the present case only two fibre lengths have been tried. However it is expected that for given compacted density an optimum fibre length can be arrive at, which mobilizes the optimum strength of the fibre.

To have a better idea on the effect of fibre inclusion on the strength parameters of the compacted pond ash, the shear strength parameters of the specimens i.e. the unit cohesion and angle of internal friction are expressed in non-dimensional parameters of ‘normalized cohesion' and 'normalized coefficient of friction'. The normalized cohesion is defined as the ratio of unit cohesion value of fibre reinforced pond ash specimens to the unit cohesion value of unreinforced pond ash specimens at a given density and moisture content. Similarly, the normalized coefficient of friction is defined as the ratio of frictional coefficient value of fibre reinforced pond ash specimens to the frictional coefficient value of unreinforced pond ash specimens at a given density and moisture content. The variation of normalized cohesion with fibre content for fibre length of 6mm and 12mm is shown in Fig.4.18, whereas Fig.4.19 gives the variation of normalized coefficient of friction with fibre content.

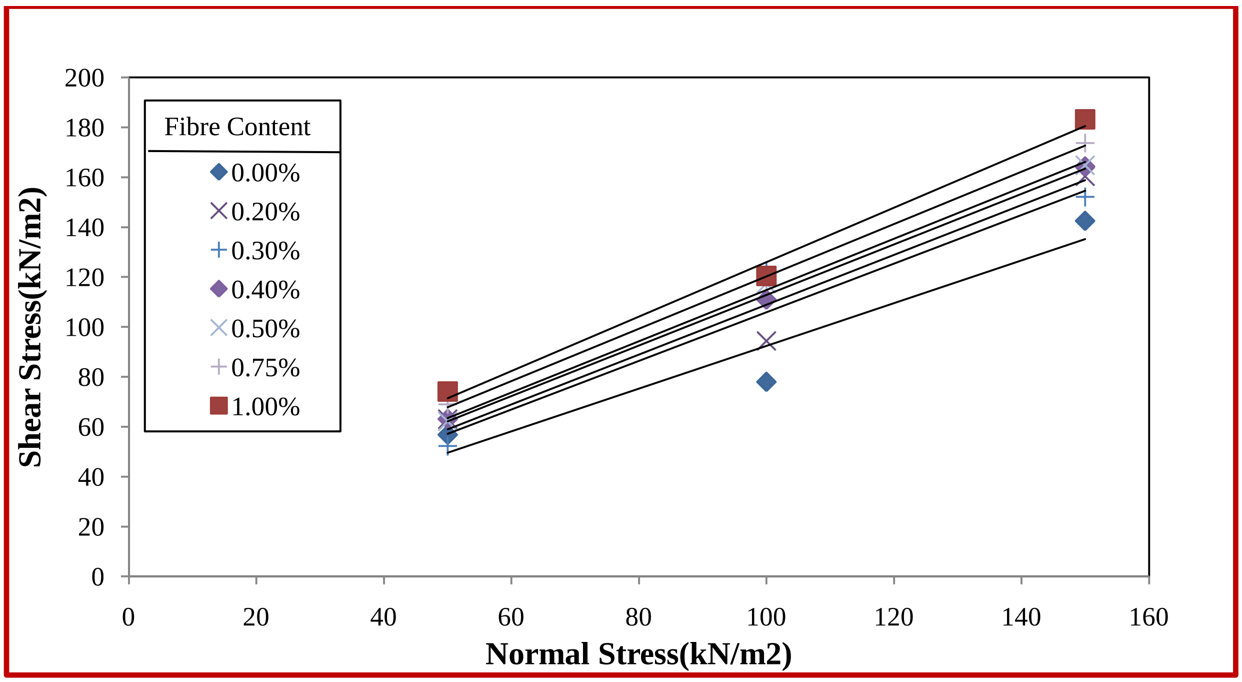

Fig.4.12 Typical normal stress versus shear stress plots for reinforced (6mm fibre) pond ash at standard proctor density

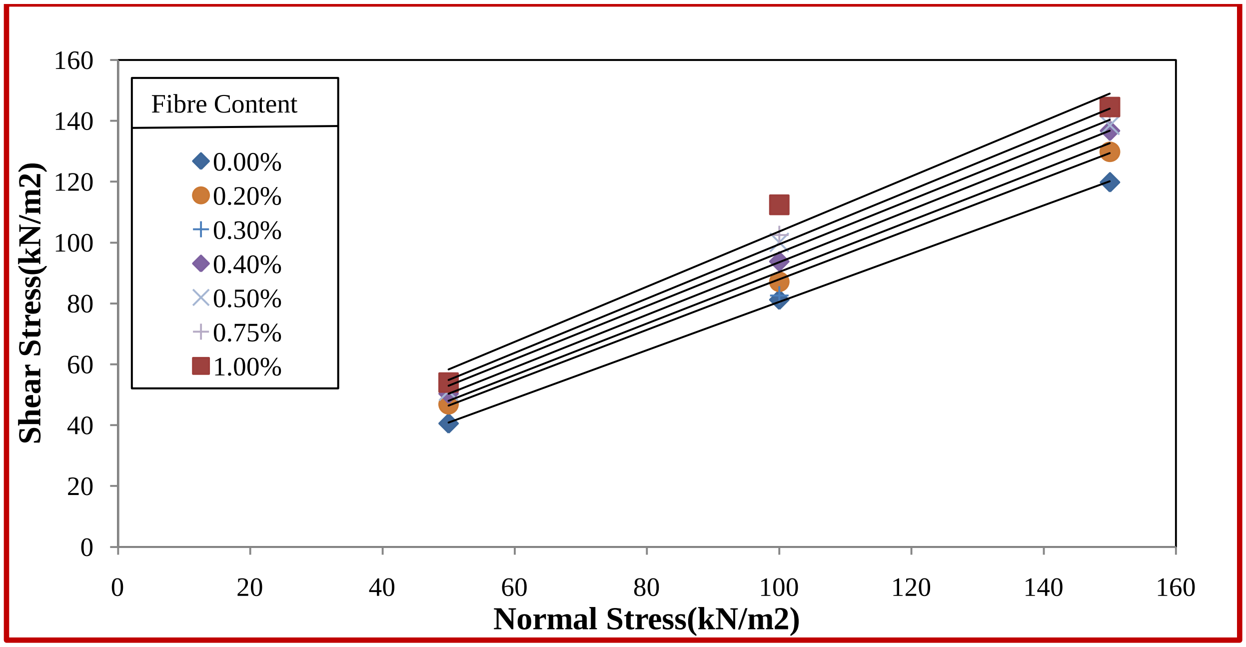

Fig.4.13 Typical normal stress versus shear stress plots for reinforced (6mm fibre) pond ash at modified proctor density

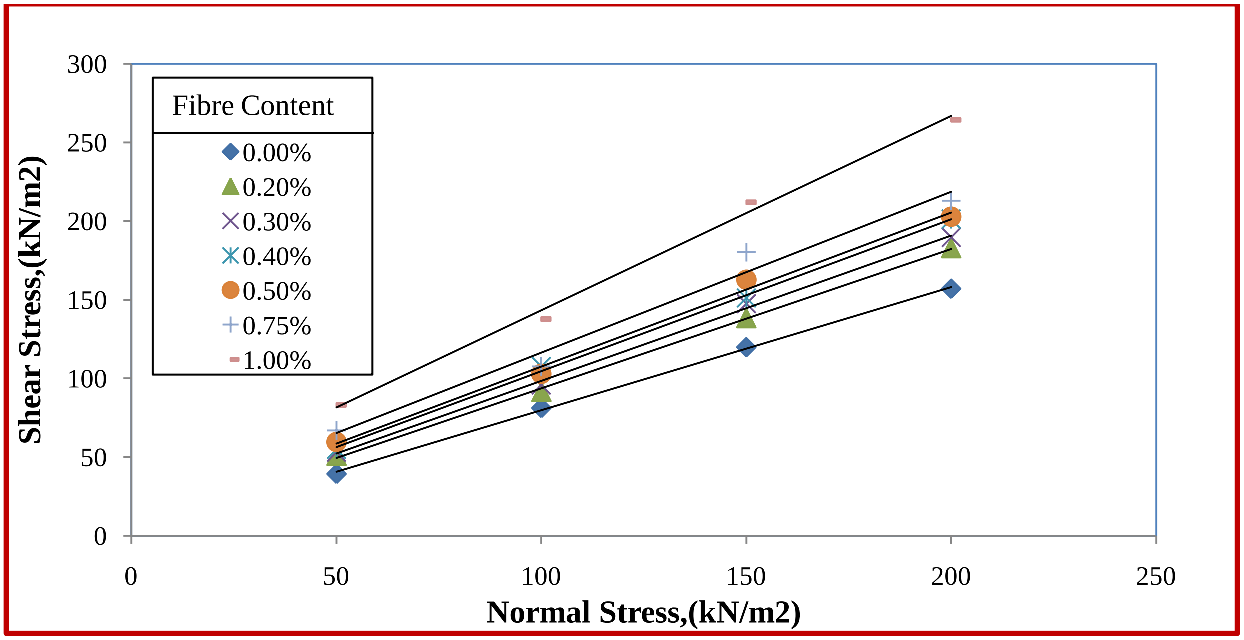

Fig.4.14 Typical normal stress versus shear stress plots for reinforced (12mm fibre) pond ash at standard proctor density

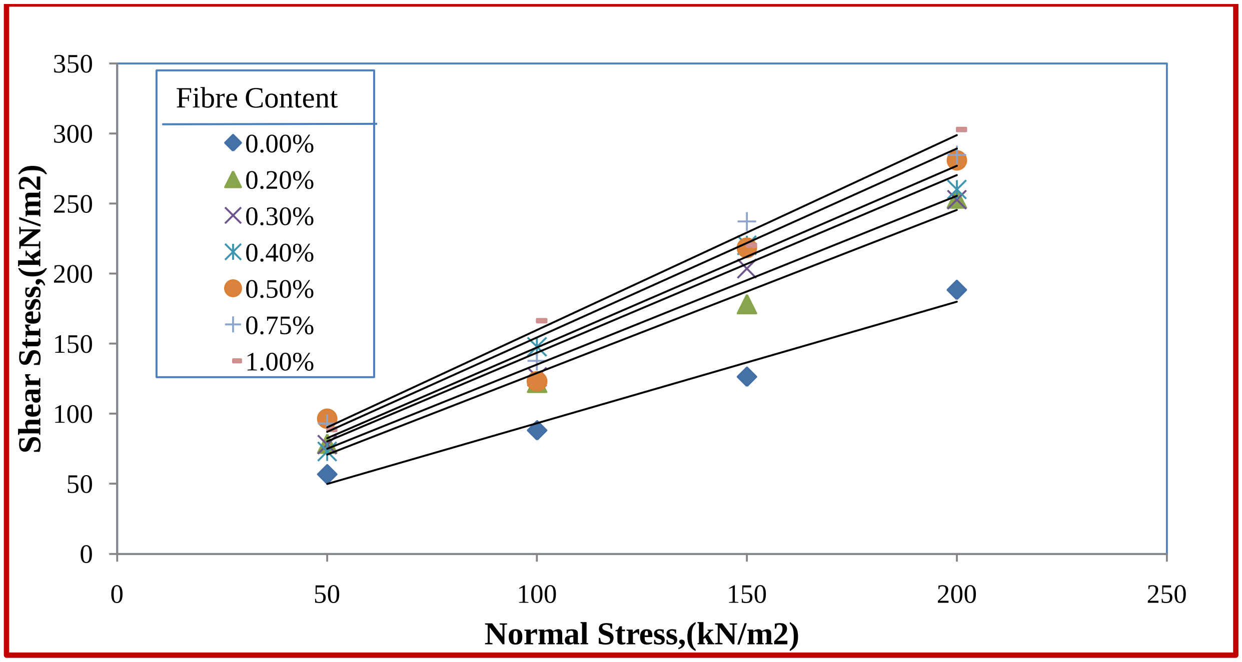

Fig.4.15 Typical normal stress versus shear stress plots for reinforced (12mm fibre) pond ash at modified proctor density

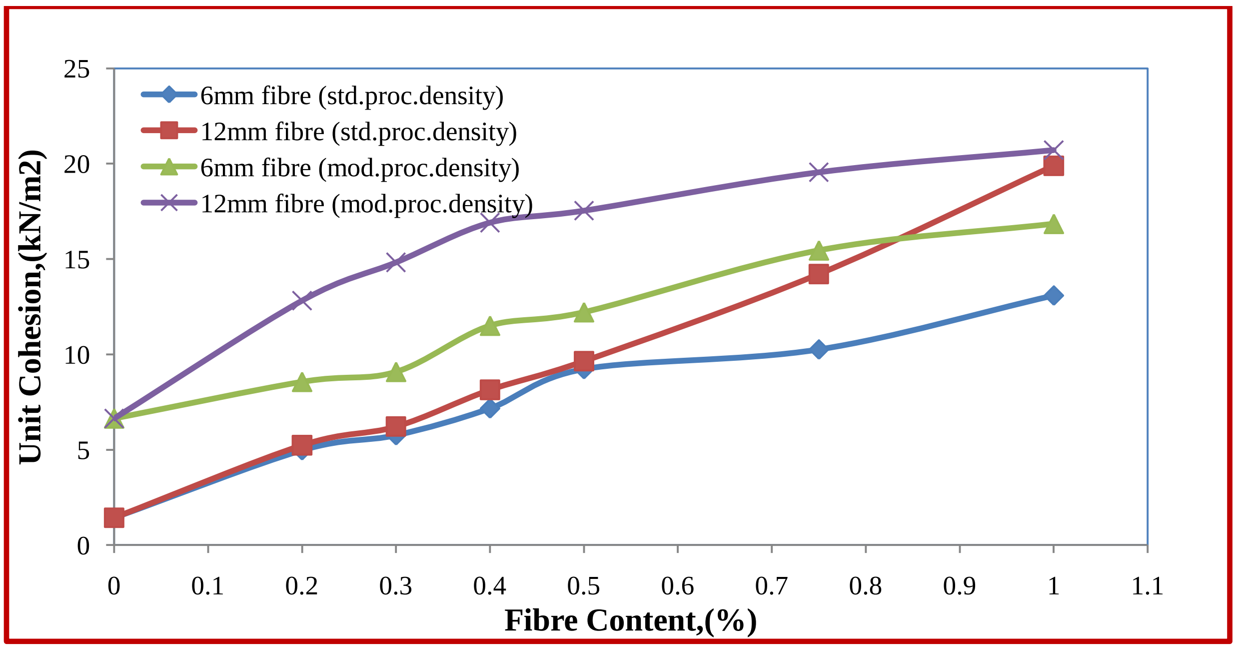

Fig.4.16 Variation of unit cohesion with fibre content for reinforced (6mm &12mm fibre) pond ash at standard & modified proctor density

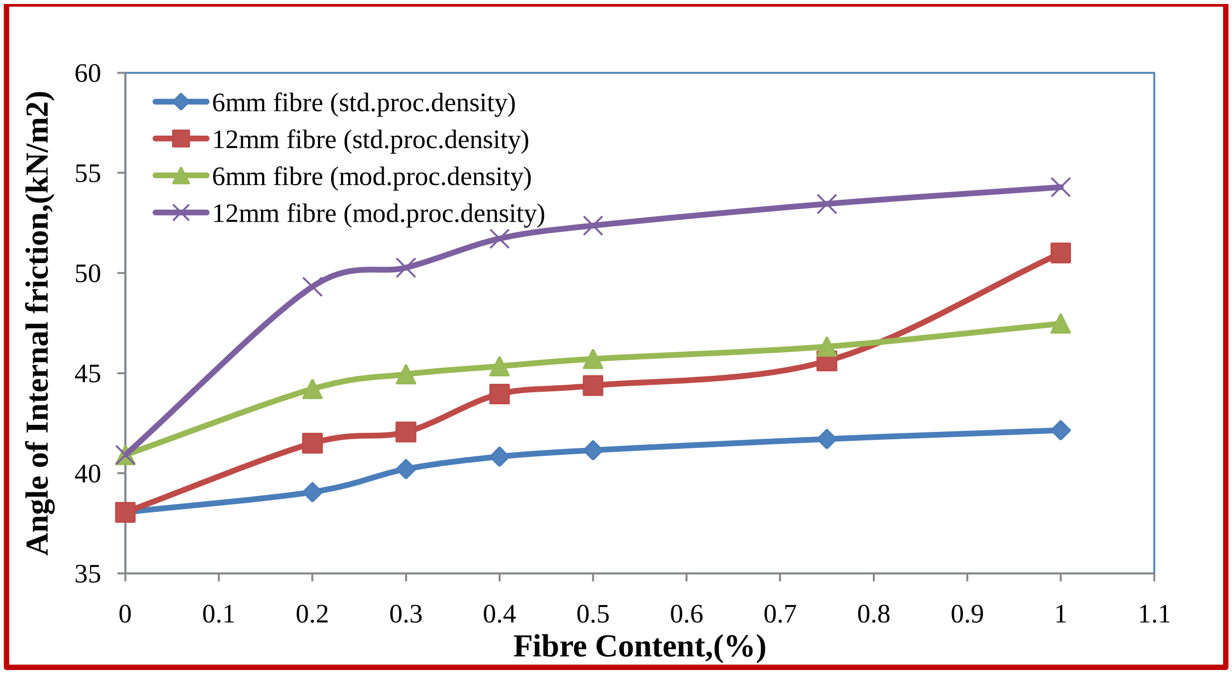

Fig.4.17 Variation of angle of internal friction with Fibre content for reinforced (6mm &12mm) pond ash at standard & modified density

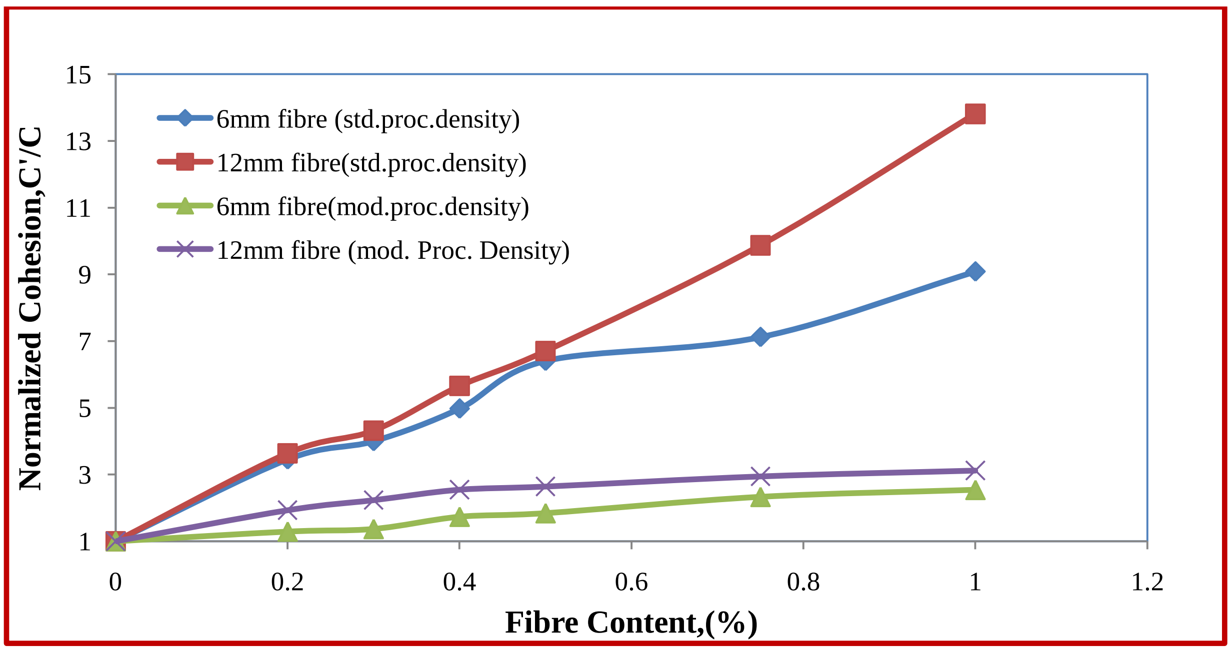

Fig.4.18 Fibre content versus normalized cohesion (c'/c) plots of reinforced (6mm & 12mm) pond ash at standard and modified proctor density

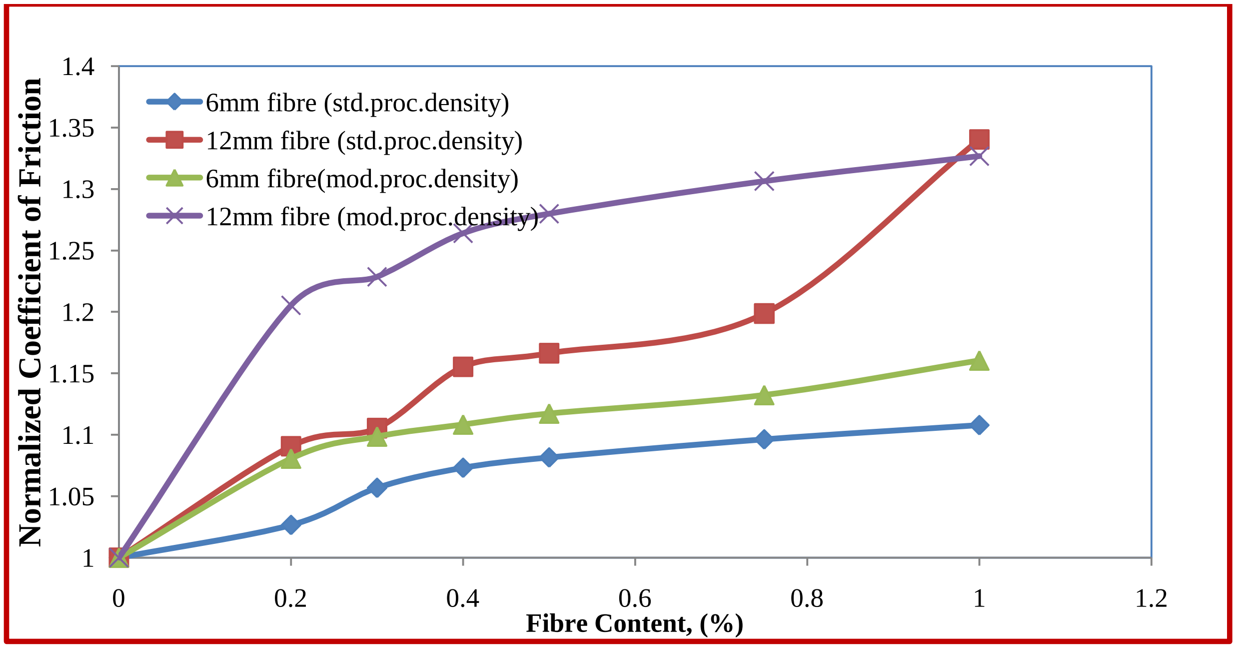

Fig.4.19 Fibre content versus normalized coefficient of friction plots of reinforced (6mm & 12mm) pond ash at standard and modified proctor density

4.3.3 Unconfined Compressive Strength

4.3.3.1 Effect of compaction energy

Unconfined compressive strength tests were carried out on unreinforced pond ash specimens compacted to their corresponding MDD at OMC with compactive effort varying as 357, 595, 1493, 2674, 2790 and3488kJ/m3. Stress-strain relationships of compacted pond ash were presented in Fig.4.20. Form these plots it is observed that the failure stress as well as initial stiffness of samples, compacted with greater compaction energy, are higher than the samples compacted with lower compaction energy. However in general the failure strains are found to be lower for samples compacted with higher energies. The failure strains vary from a value of 0.75 to 1.75%, indicating brittle failures in the specimens. The increase in unconfined strength and initial stiffness of specimens with increased compactive effort is attributed to the closer packing of particles, resulting in the increased interlocking among particles. A closer packing is also responsible in increasing the cohesion component in the sample. A nonlinear relationship is found to exist between the unconfined strength and compactive effort (Fig.4.21). Similar relationship is found to exist between strength ratio and compaction energy ratio (Fig.4.22). This shows that the strength of compacted specimens can be enhanced by increasing the compactive effort. Deformation modulus is one of the important parameter used for the design of pavement. It is a key factor for estimating the settlement of foundation resting on pond ash fill or embankments made of compacted pond ash. The relationship of deformation modulus as a function of unconfined strength is generally required for design purposes. Figs.4.24 and 4.25 illustrates the relationships between initial tangent modulus (E_i)with unconfined compressive strength and secant modulus (E_{s50}).It revealed from the test results that a linear relationship exists between the initial tangent modulus with unconfined compressive strength and deformation modulus.

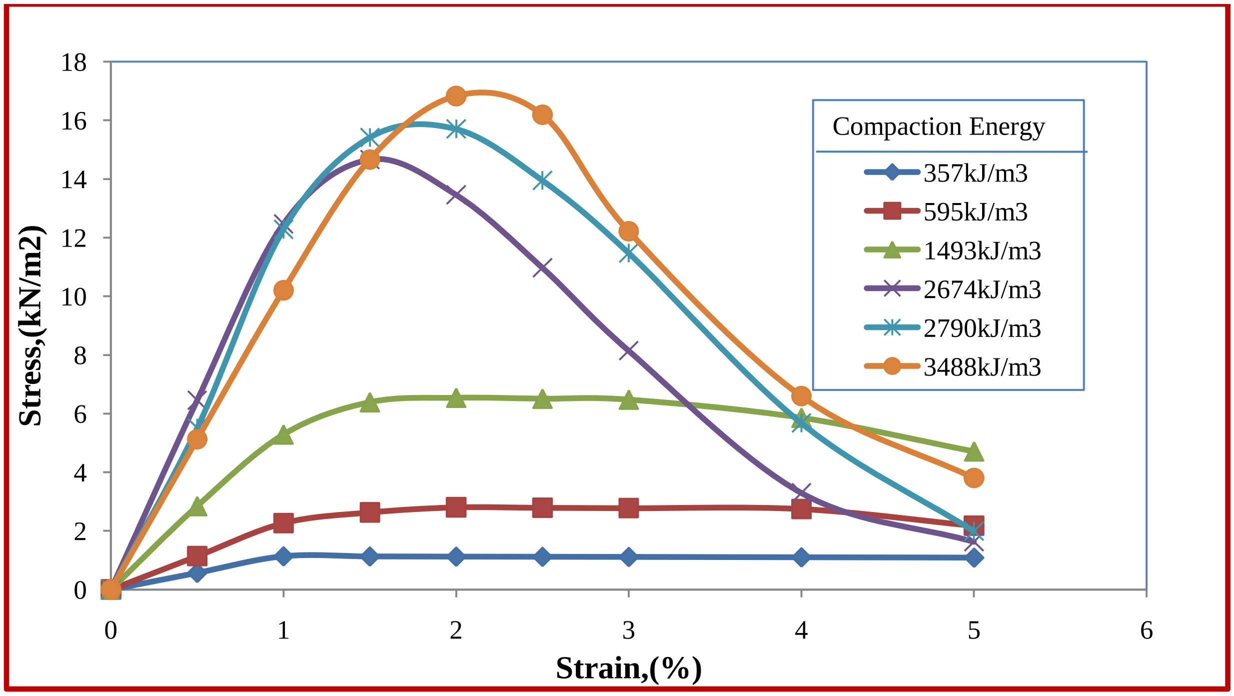

Fig.4.20 Stress~strain relationship of compacted pond ash specimens.

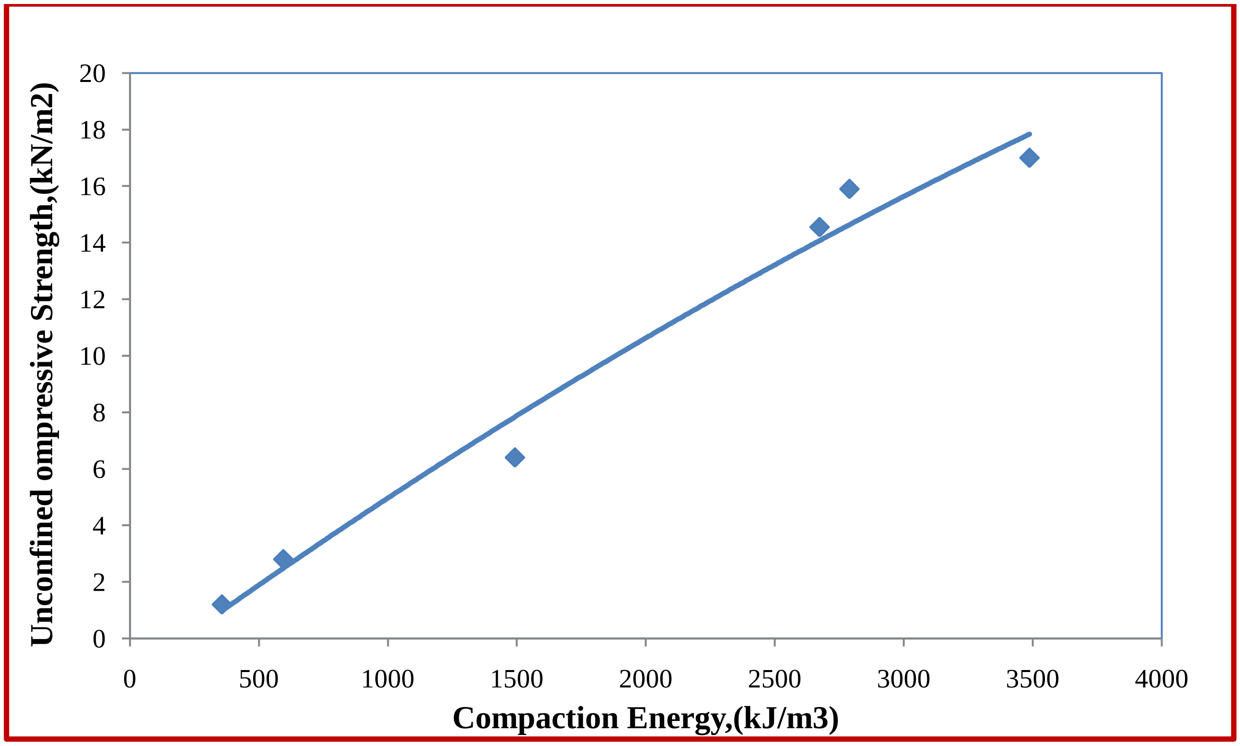

Fig.4.21 Variation of unconfined compressive strength with compaction energy.

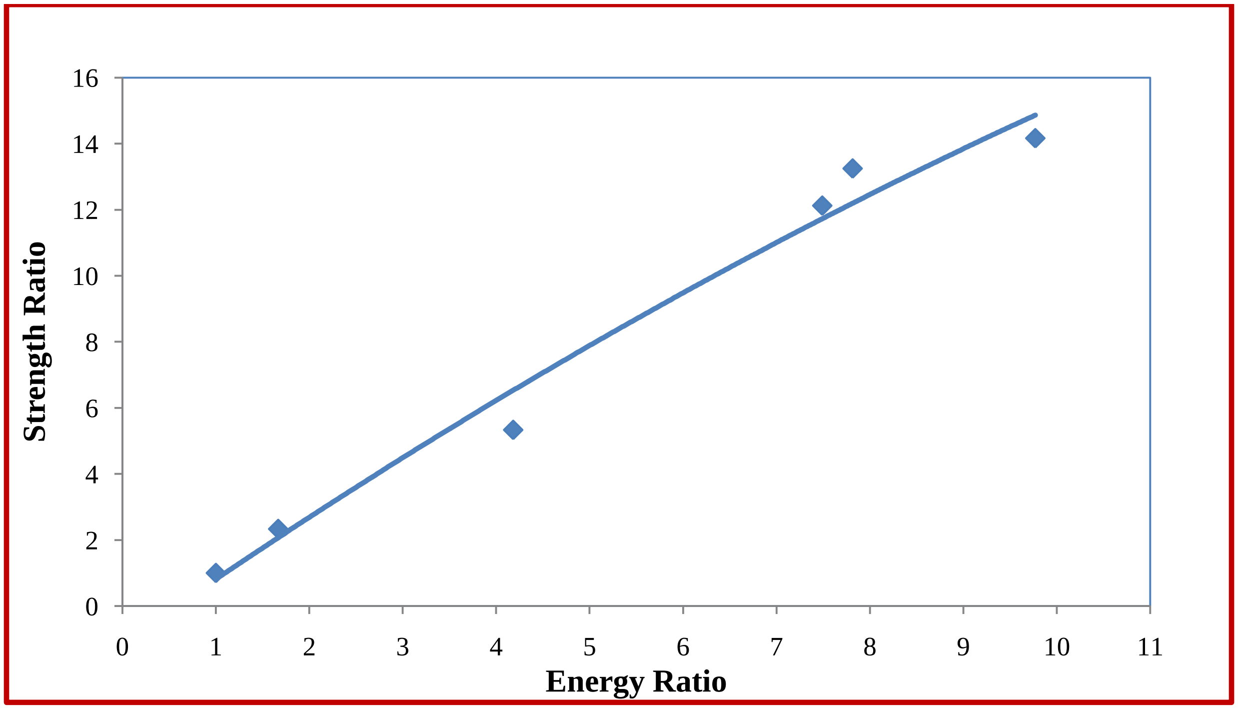

Fig.4.22 Relationship between energy ratio and strength ratio of compacted specimens.

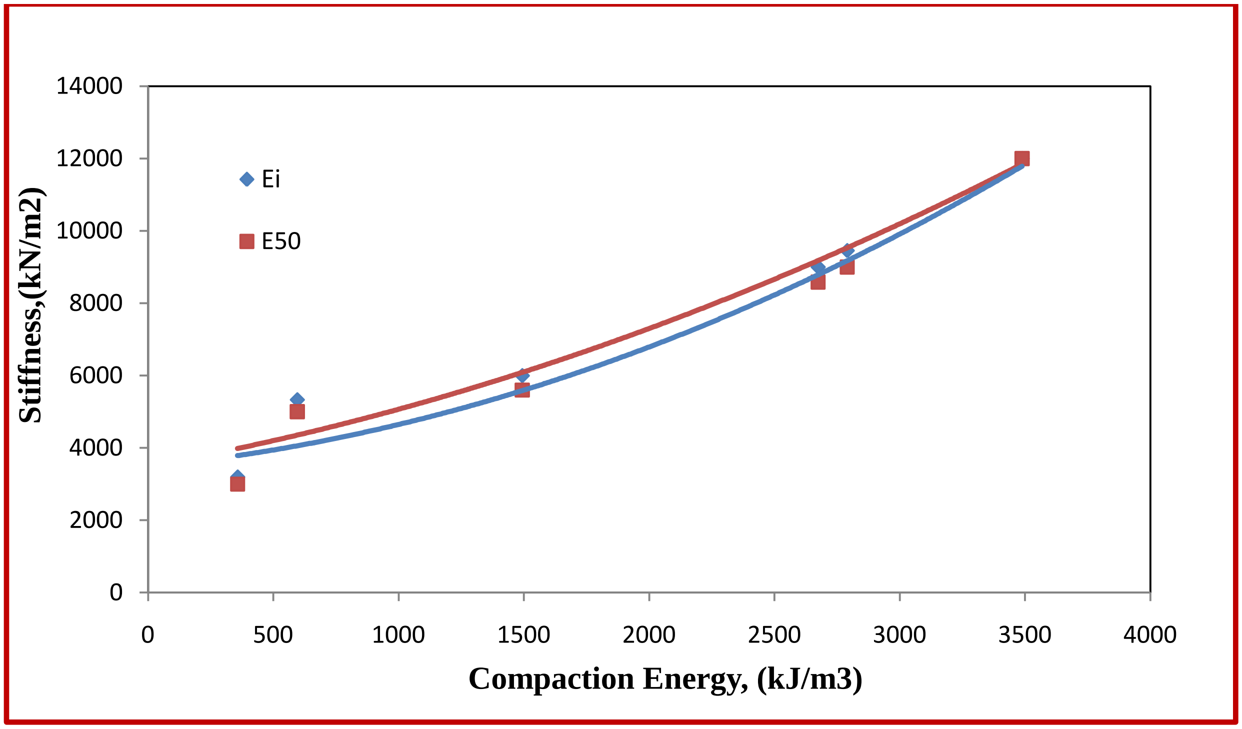

Fig.4.23 Variation of tangent modulus with compaction energy.

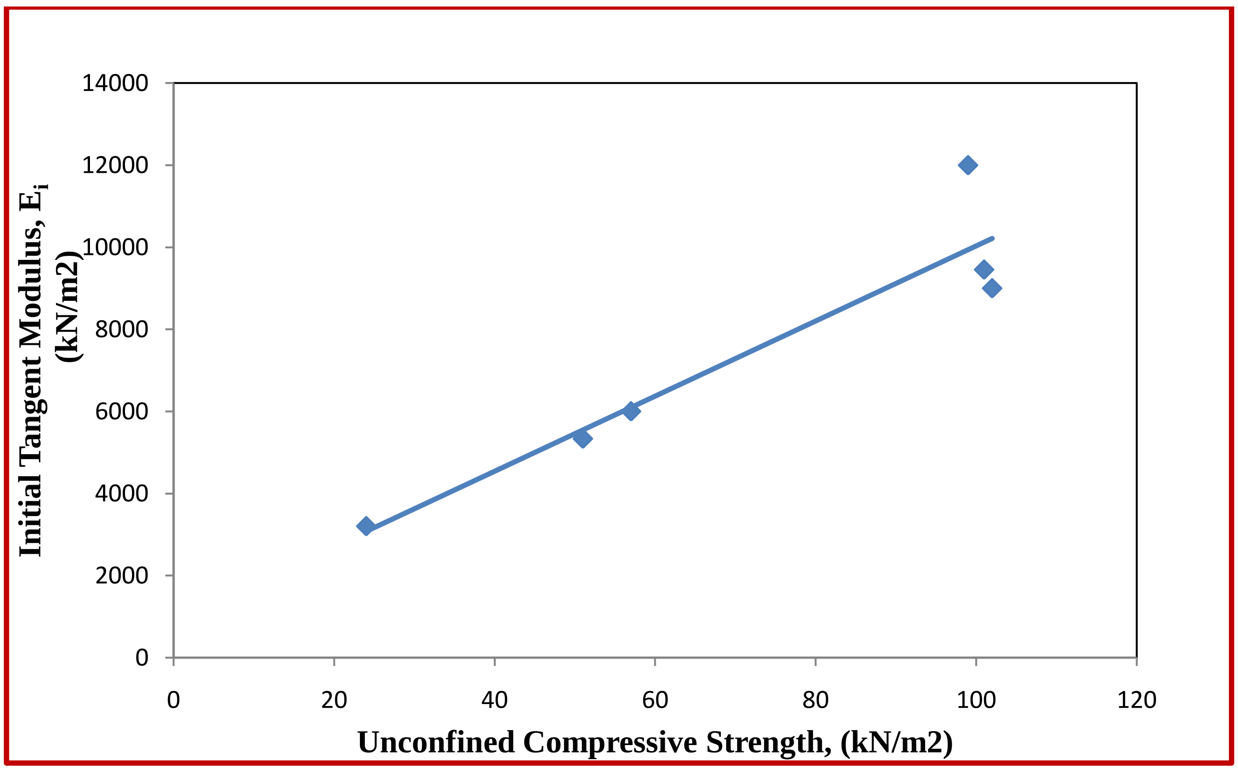

Fig.4.24 Initial tangent modulus versus unconfined compressive strength.

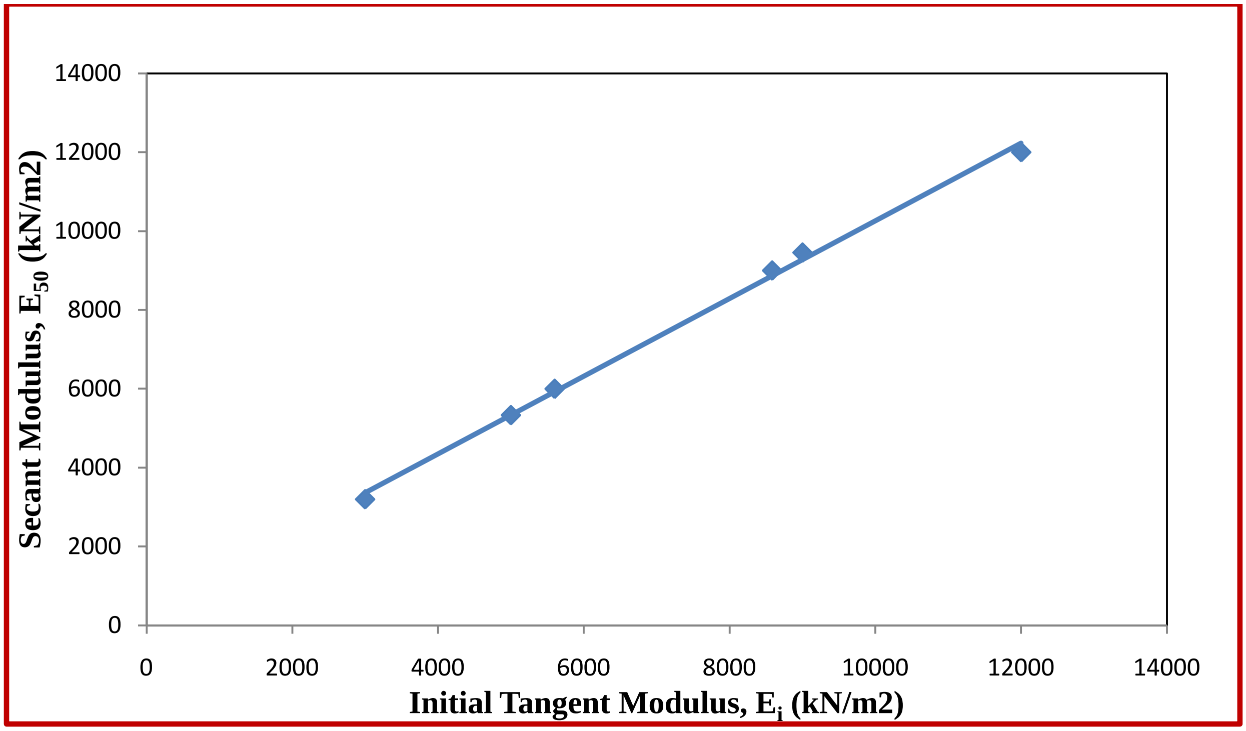

Fig.4.25 Secant modulus at 50% of failure stress versus Initial tangent modulus.

4.3.3.2 Effect of fibre content

The unconfined compressive strength of the pond ash specimens reinforced with two different sizes of fibres that is 6mm and 12mm length were determined for specimens compacted to standard and modified proctor density with different percentage of fibre (i.e. 0.1%,0.2%, 0.3%, 0.4%, 0.5%, 0.75%, and 1.0%). Fig.4.26 and Fig.4.27 shows the stress ~ strain relationship of reinforced (6mm fibre) pond ash specimens at standard and modified proctor density respectively. Similarly, Fig.4.28 and Fig. 4.29 is presented the stress~strain relationship of reinforced (12mm fibre) pond ash specimens at standard and modified proctor density respectively. Variation of unconfined compressive strength with fibre content for reinforced (6mm &12mm) pond ash at standard & modified proctor density is presented in Fig. 4.30. The unconfined compressive strength of specimens is found to increase with the fibre content. However, the rate of increase of strength with fibre content is not linear. Initially the rate of increase is high thereafter the same is not that much prominent. Randomly oriented discrete inclusions incorporated into granular materials improve its load – deformation behavior by interacting with the soil particles mechanically through surface friction and also by interlocking. The bonding and interlocking between the granular particle and reinforcement facilitates the transfer of the tensile strain developed in the mass to the reinforcement and thus, the tensile strength of the reinforcement is mobilized and helps in improving the load capacity of the reinforced mass. The test result shows that the failure stress of reinforced specimen's increases with fibre content both for standard and modified proctor density. The plots also reveal that at given compacted density and fibre content, the 12mm size fibre gives higher strength than 6mm size fibres. The fibres modifies the stress condition in the specimens and transfer the shear along the failure plane to the surrounding mass by combined effect of adhesion and friction between the fibre and ash particles. For shorter fibres (6mm) sufficient anchorage to fibre might not be developed leading to pull-out failure and lesser mobilization of fibre capacity. In the present case only two fibre lengths have been tried. However it is expected that for given compacted density an optimum fibre length can be arrive at, which mobilizes the optimum strength of the fibre.

To have a better idea on the effect of fibre inclusion on the unconfined compressive strength of the compacted pond ash, the unconfined compressive strength is expressed in non-dimensional parameters of normalized unconfined compressive strength. The normalized unconfined compressive strength is defined as the ratio of unconfined compressive strength value of fibre reinforced pond ash specimens to that of unreinforced specimens at a given density and moisture content. The variation of normalized unconfined compressive strength with fibre content for fibre length of 6mm and 12mm is shown in Fig.4.31. The normalized unconfined compressive strength is found to be 1.9 and 1.4 for samples reinforced with 1% fibre content and with 6mm fibres to their standard and modified proctor density respectively. Whereas, these values are 2.7 and 2.4 for samples reinforced with 12mm fibres at fibre content of 1 %. This clearly indicates that the compressive strength of samples can be improved with inclusion of discrete fibres and for the present test condition 12mm fibres are found to more effective in increasing the compressive strength than 6mm fibres.

The stress ~ strain curves as given in Fig.4.26 to Fig.4.29 clearly indicates that at a given density and increase in fibre content results in decrease of initial stiffness whereas the failure strain increases. This indicates that inclusion of fibre give ductility to the specimens. It can further be notice that reduction in post peak strain of a reinforced sample is comparatively lower than the unreinforced sample. These properties are highly advantages for structures subjected to dynamic or earthquake loading.

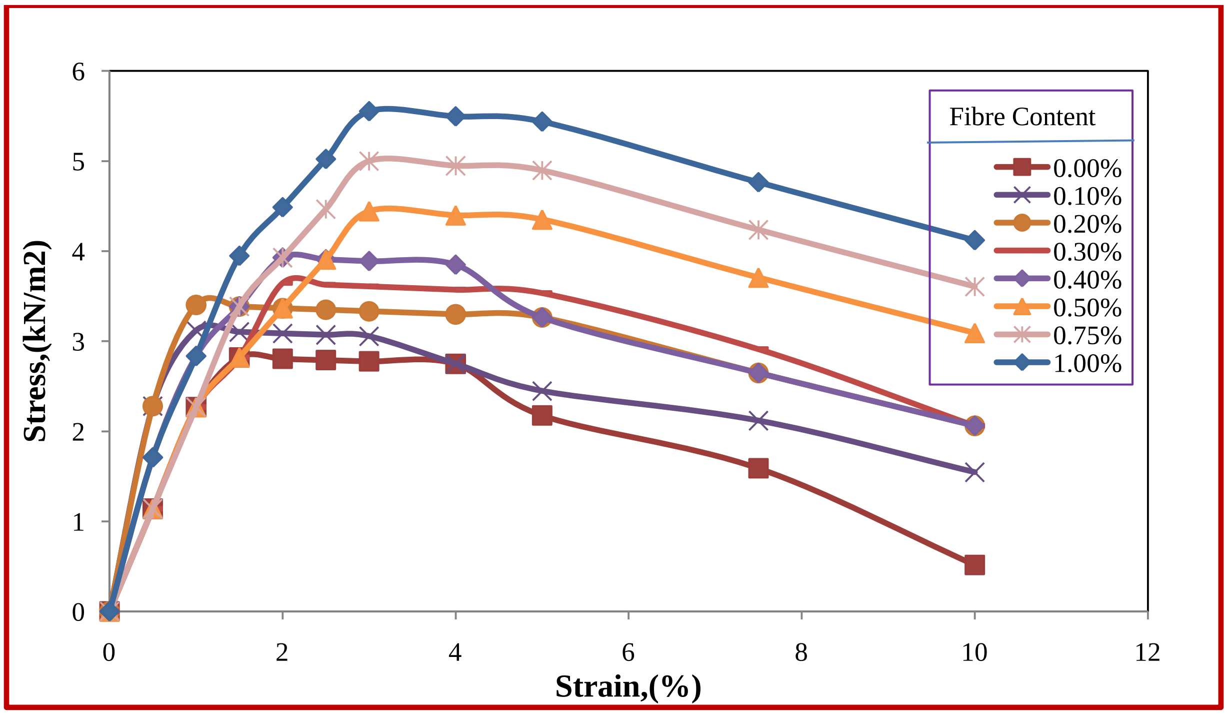

Fig.4.26 Stress~strain relationship of reinforced (6mm fibre) pond ash specimens at standard proctor density

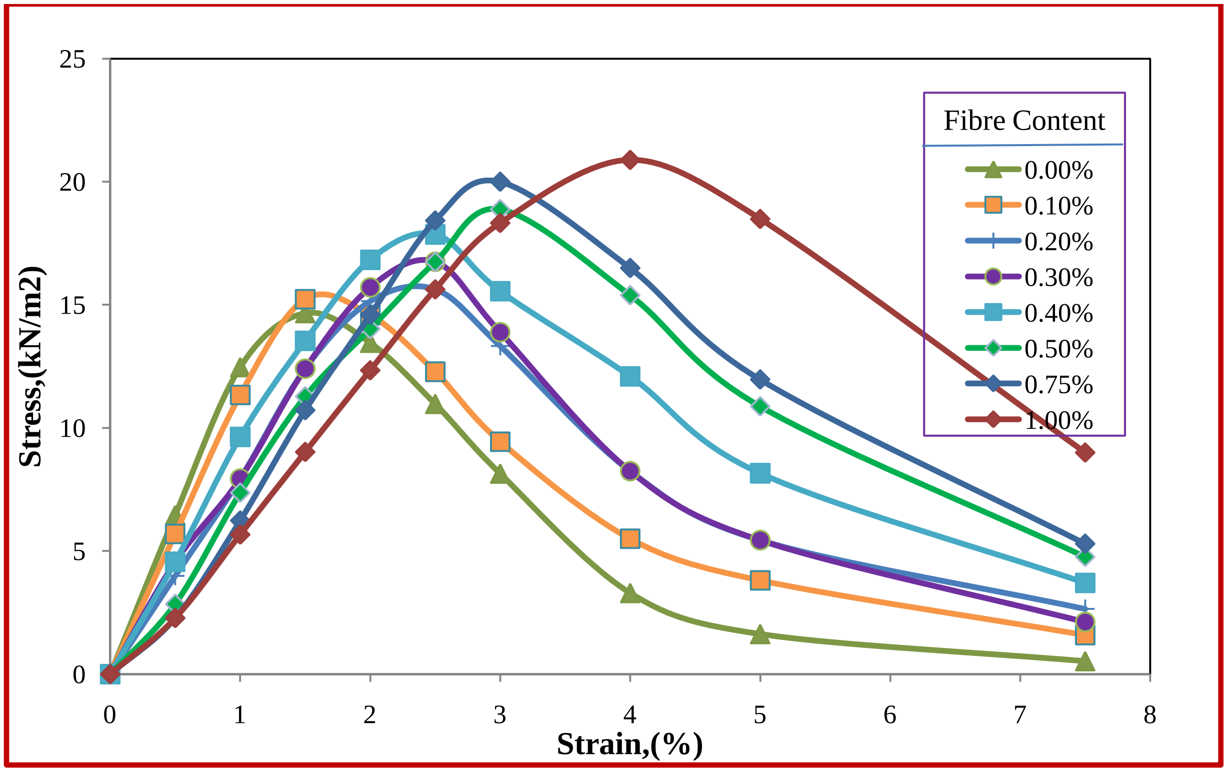

Fig.4.27 Stress~strain relationship of reinforced (6mm fibre) pond ash specimens at modified proctor density

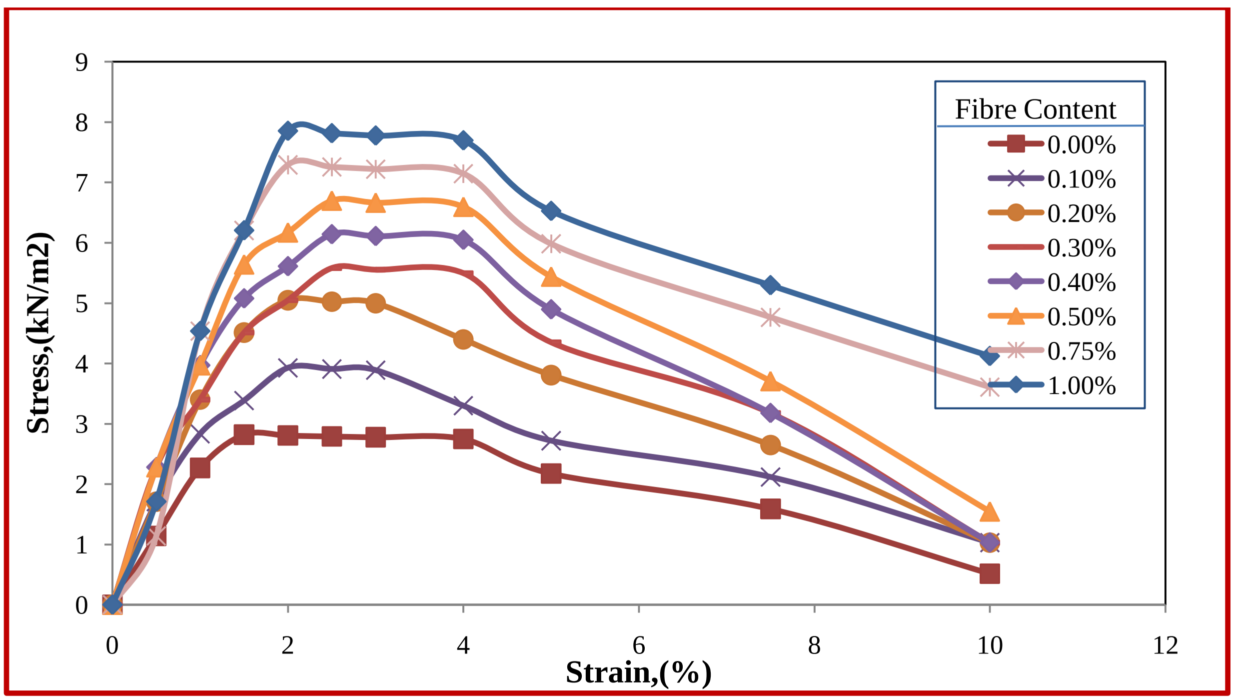

Fig.4.28 Stress~strain relationship of reinforced (12mm fibre) pond ash specimens at standard proctor density

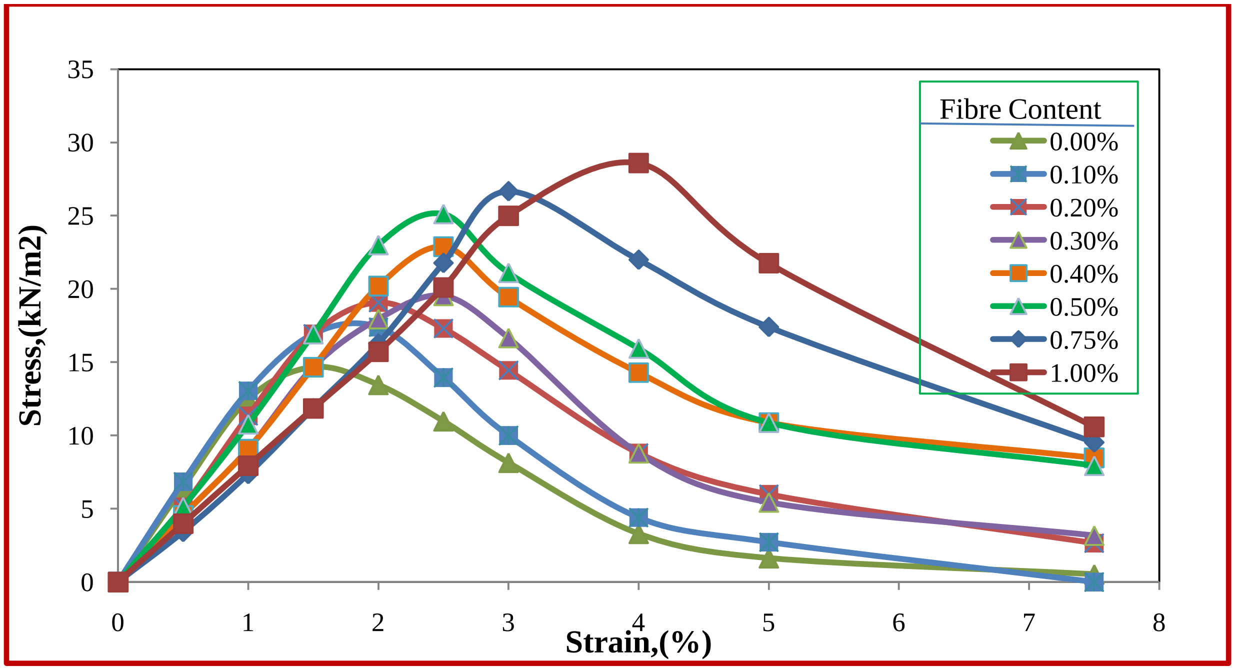

Fig.4.29 Stress~strain relationship of reinforced (12mm fibre) pond ash specimens at modified proctor density

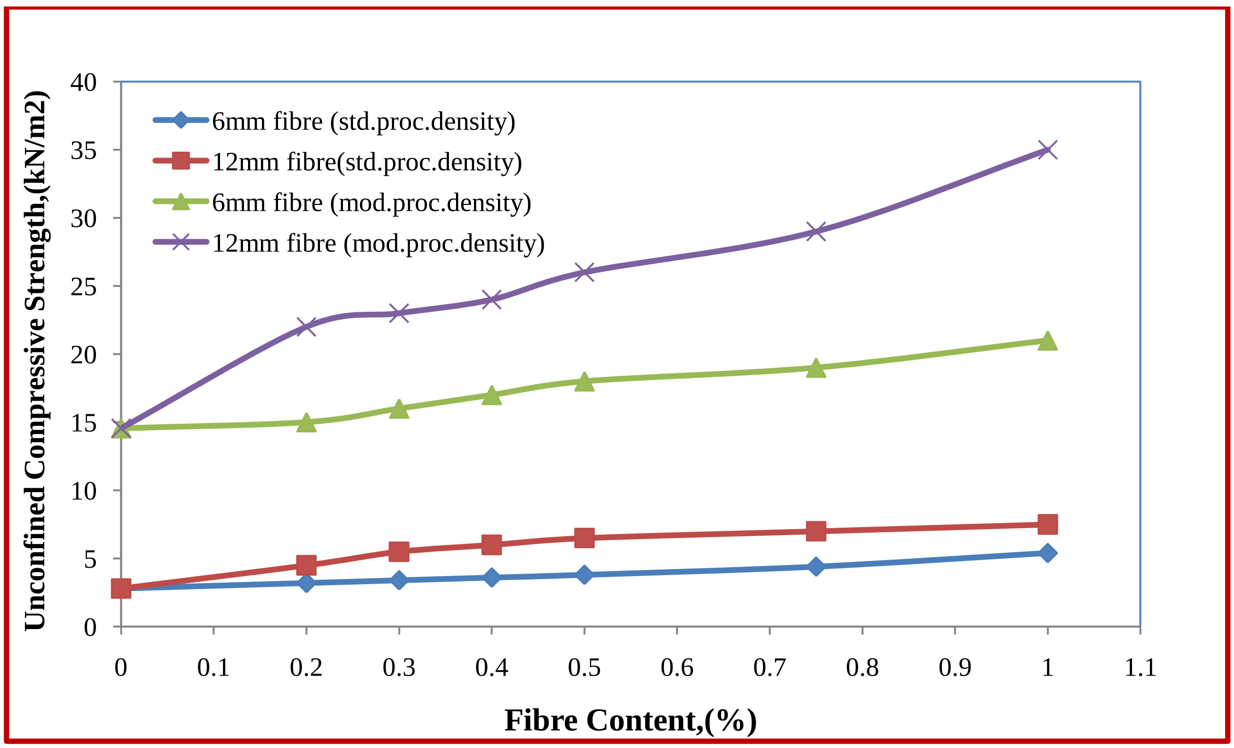

Fig.4.30 Variation of unconfined compressive strength with fibre content for reinforced (6mm &12mm) pond ash at standard & modified proctor density

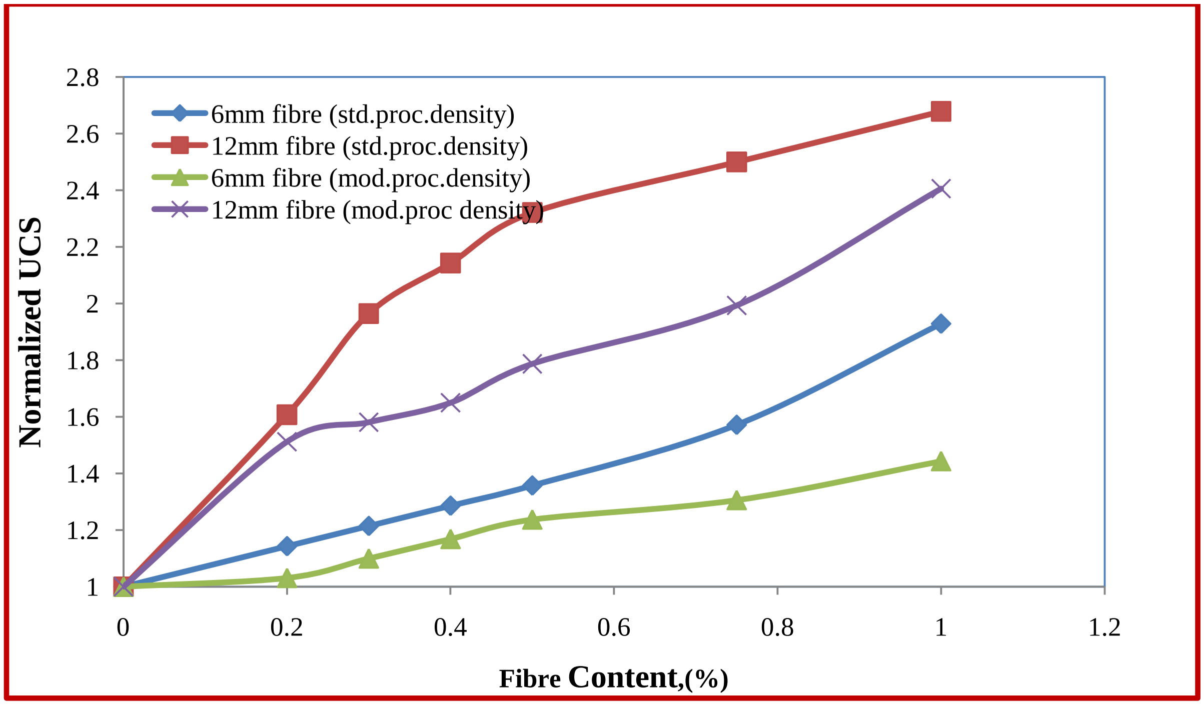

Fig.4.31 Variation of normalized unconfined compressive strength with fibre content for reinforced (6mm &12mm) pond ash at standard & modified proctor density

4.3.3.3 Effect of degree of saturation

The effect of degree of saturation on unconfined compressive strength were studied by varying the moulding moisture content from 7.19 to 35.92% for samples compacted at standard Procter density (11.08kN/m^3) and from 5.66 to 36.79% for samples compacted at modified Procter density (12.40kN/m^3). The variations of stress and strain for the above mentioned conditions are given in Figs. 4.32 & 4.33 respectively. Plots between variation of failure strain with moisture content (Fig.4.34) show that the failure strain increases with degree of saturation up to OMC and thereafter, the same as in constant at both in standard and modified proctor density. However, in Fig.4.35 it shows variation of unconfined compressive strength with moisture content. When the percent of water content reduces from the optimum moisture content the unconfined compressive strength increases at a sustained degree of saturation of 13% and 14 % and then, decreases in standard and modified proctor density, it is due to the added water lubricates the surface of ash particles. Pond ash which is non-plastic in nature possess no inter-particular attraction (cohesion), however the compacted samples of specimens posses negligible amount of cohesion (pseudo-cohesion/apparent cohesion) due to surface tension effect. The apparent cohesion of compacted specimens of pond ash becomes zero as the sample becomes completely dry or fully saturated, with the peak apparent cohesion in between. So, in the presence case the maximum unconfined compressive strength is observed at of degree of saturation of 13% and 14 % of the specimens.. This is obvious because most of the ash particles are rounded/sub-rounded in shape, devoid of any interlocking properties.

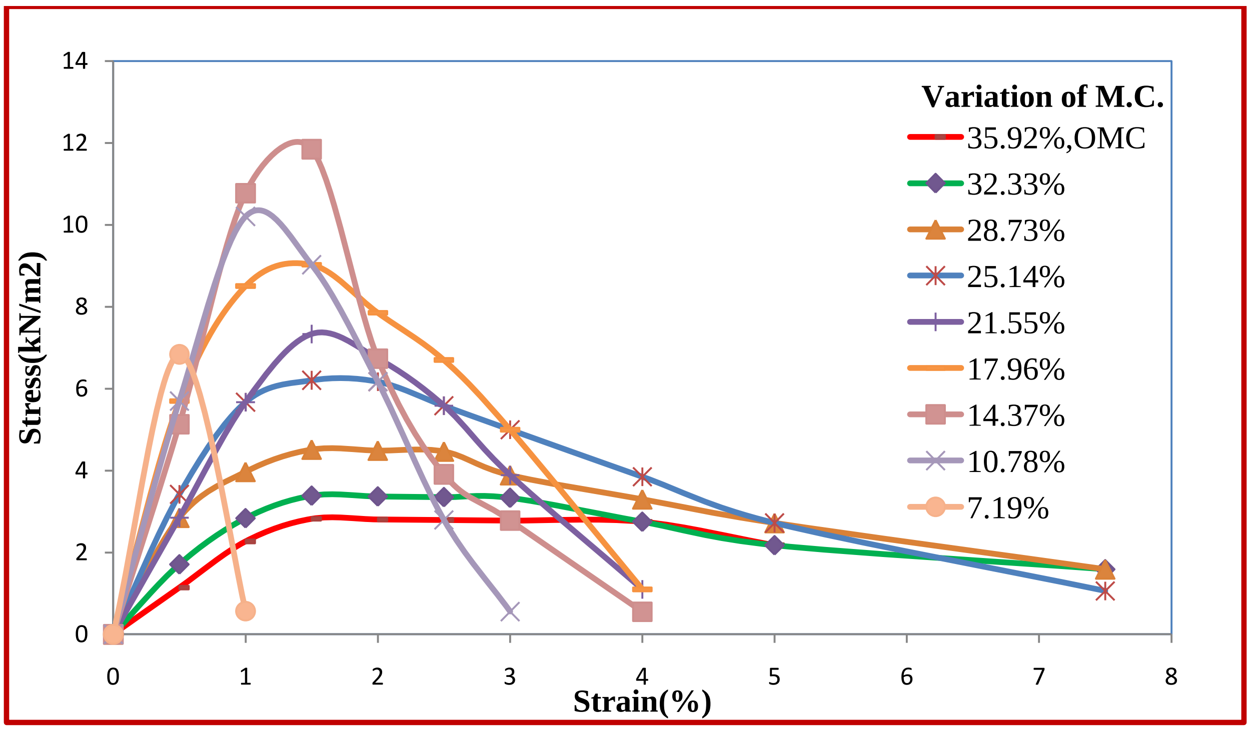

Fig.4.32 Stress-Strain relationship of compacted pond ash specimens with moisture content at MDD=11.08 kN/m^3.

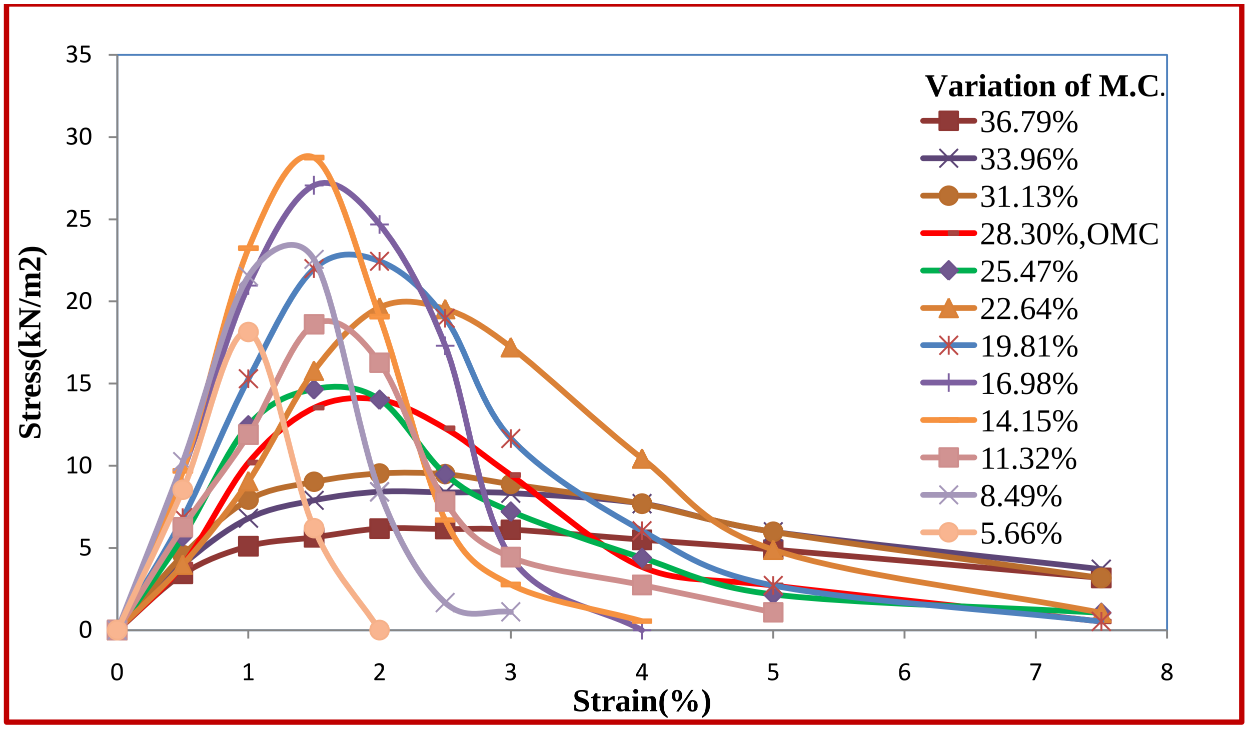

Fig.4.33 Stress-Strain relationship of compacted pond ash specimens with moisture content at MDD=12.40 kN/m^3.

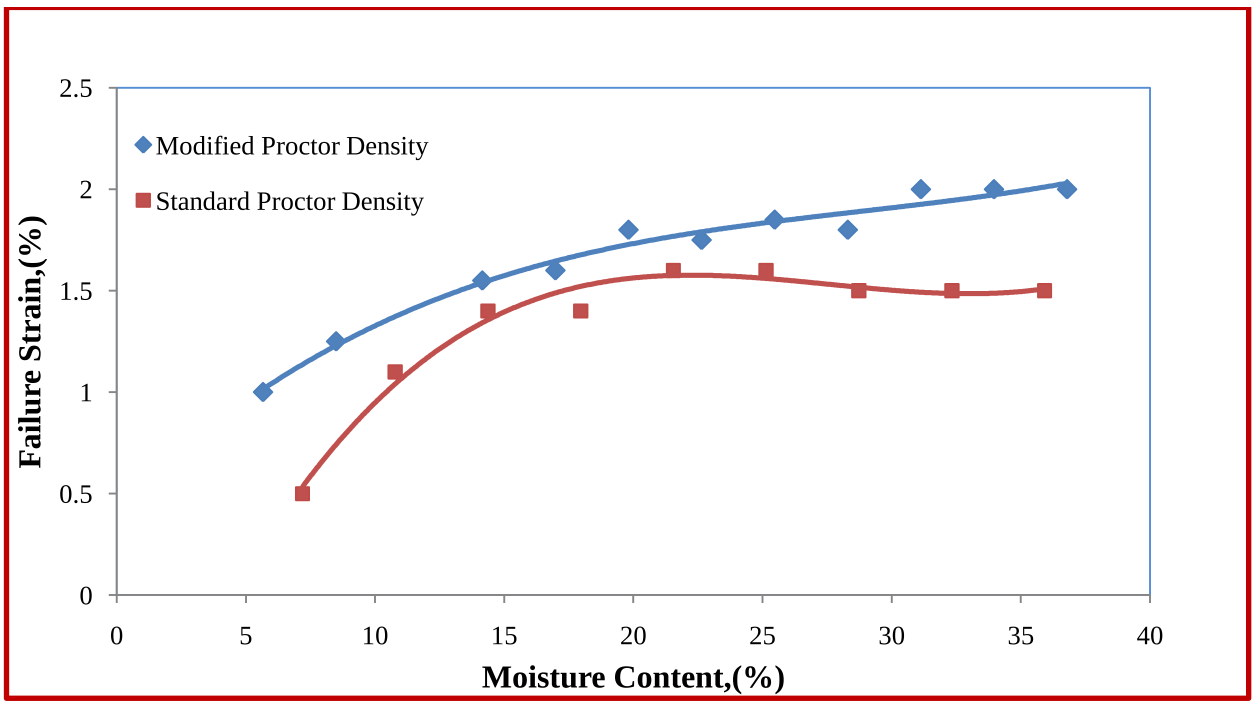

Fig.4.34 Variation of failure strain with moisture content.

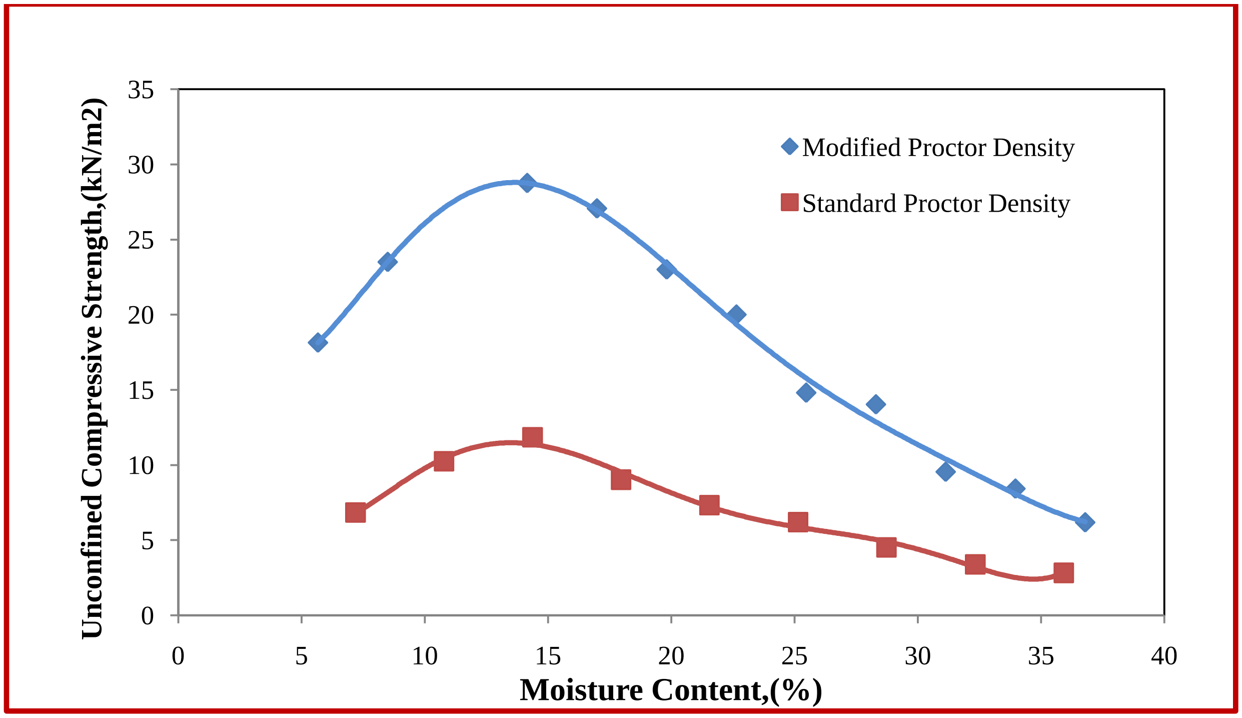

Fig.4.35 Variation of unconfined compressive strength with moisture content.

4.3.4 CBR Value

CBR-value is used as an index of soil strength and bearing capacity. This value is broadly used and applied in design of the base and the sub-base material for pavement. Pond ash is often used for the construction of these pavement layers and also for embankments. CBR-test was conducted to characterize the strength and the bearing capacity of the pond ash. In the present experimental programm two series of test have been conducted in the first series, test have been conducted unreinforced pond ash specimens compacted to either standard proctor and modified density with varying degree of saturation. This is done to evaluate the degree of saturation on CBR value of the specimens. In the second series, tests were conducted on specimens of pond ash compacted to their MDD at OMC and with fibre content varying as 0%, ,0.2%,0.3%,0.4%,0.5%,0.75%, and 1%. This was done in order to evaluate the inclusion of fibres on CBR values of reinforced specimens. The test results at presented in the following sections:

4.3.4.1 Effect of degree of saturation

The effect of degree of saturation on CBR value were studied by varying the moulding water content from 3.59 to 43.10% for samples compacted at standard Procter density ($11.08kN/m^3$) and from 2.83% to 33.96% for samples compacted at modified Procter density ($12.40kN/m^3$). The load-penetration curves for pond ash were drawn in Fig4.36and Fig4.37 respectively. Plots between variation of CBR Value with moisture content (Fig.4.38) show that the CBR value increases with decrease in degree of saturation upto a water content of 4% for samples compacted at standard proctor density and 3% for samples compacted at modified proctor density, there after the CBR value decreases with moisture content. The highest CBR value is found to be 7.5% and 45% for samples compacted at standard proctor density and modified proctor density which corresponds to degree of saturation of 4% and 3% respectively .The trend observed in Fig. 4.40, the CBR value with moisture content is very much similar to that observe with unconfined compressive strength value of specimens. This shows that for a given compacted dry density higher unconfined compressive strength as well as CBR value can be obtained with moulding water content much lower than the OMC value. This highlights the influence of degree of saturation on the strength of compacted pond ash specimens.

Fig.4.39 shows that the variation of Normalized CBR with moisture content. The normalized CBR value is defined as the ratio of CBR value of pond ash specimens at given moisture content and MDD to that of CBR value of specimens compacted to MDD at OMC. The trend observed between normalized CBR value and water content very much similar to that of CBR value and moisture content of pond ash specimens. The maximum normalized CBR value is found to be for sample compacted to standard and modified proctor density with moulding water content of 4% and 3% respectively. This tells that the CBR value of the compacted pond ash samples can be retained by protecting it from ingress of water.

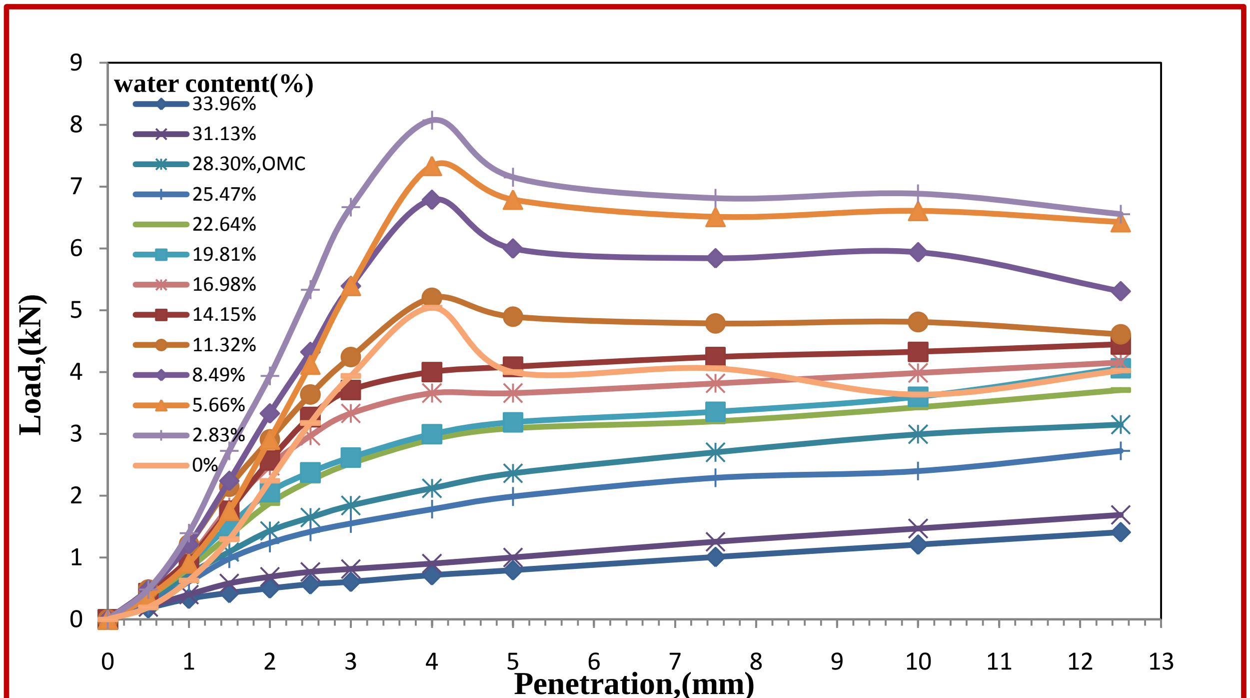

Fig.4.36 Load vs Penetration curve for different water content at dry density of 12.04kN/m^3.

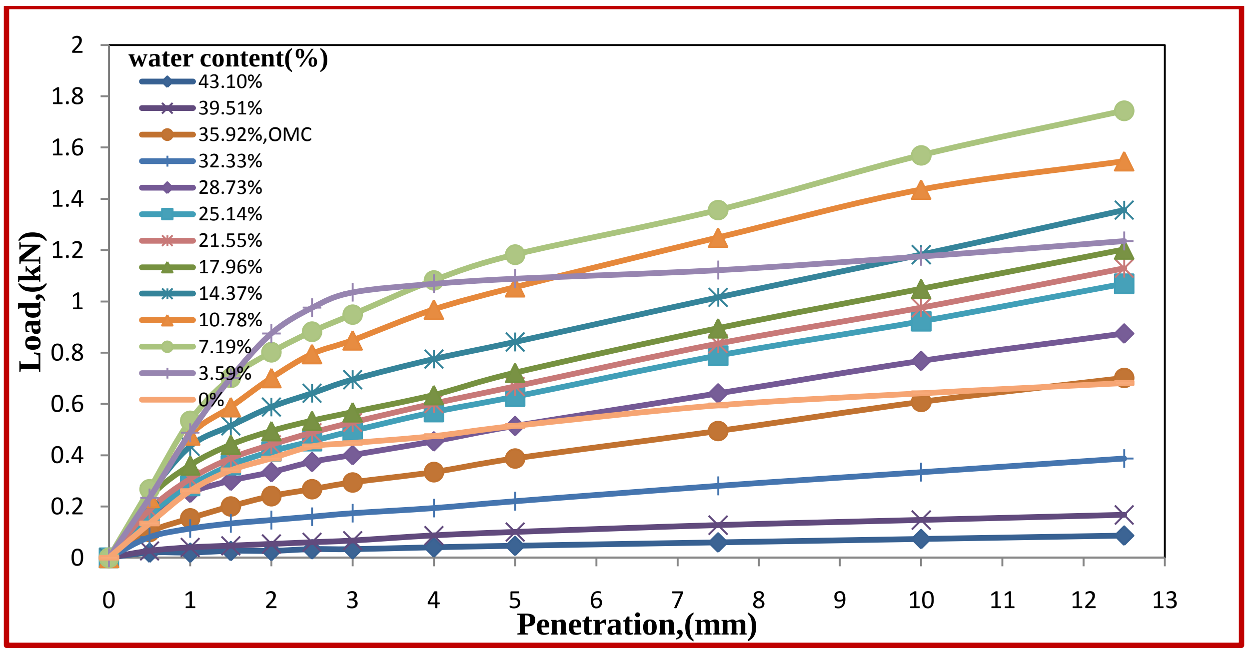

Fig.4.37 Load vs Penetration curve for different water content at dry density of 11.08kN/m^3.

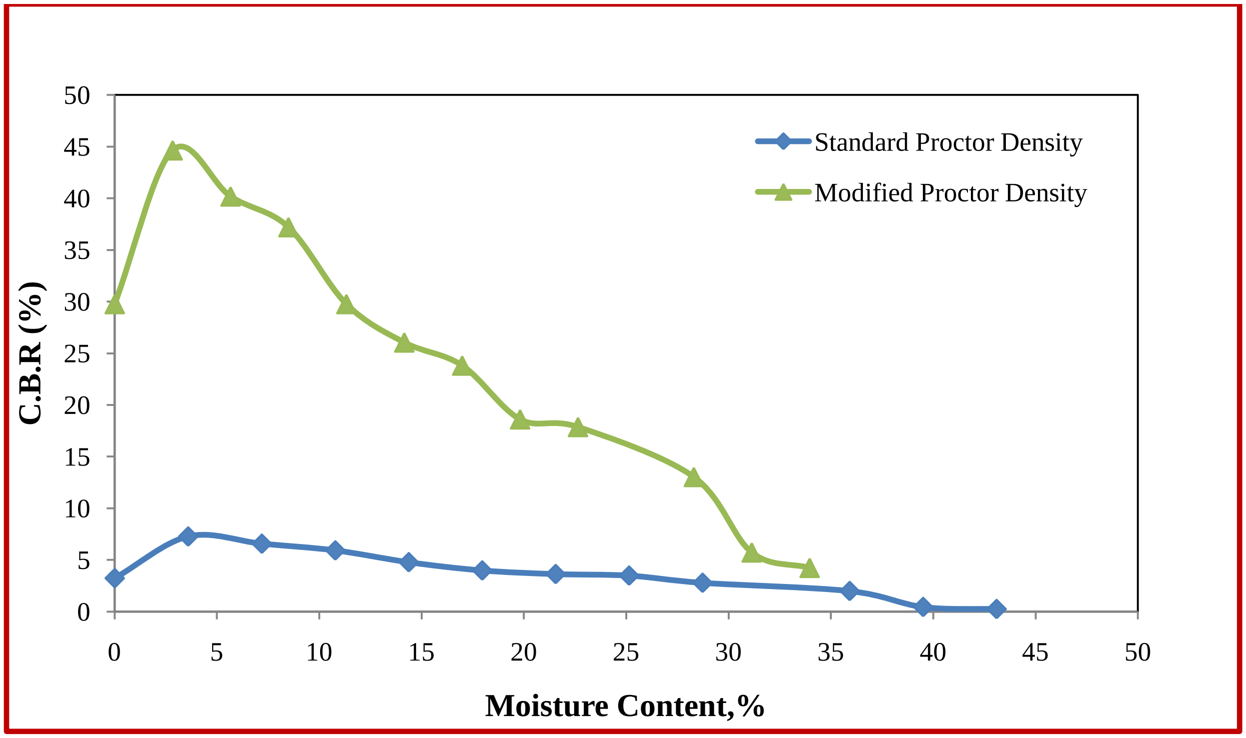

Fig. 4.38 Variation of CBR Value with moisture content.

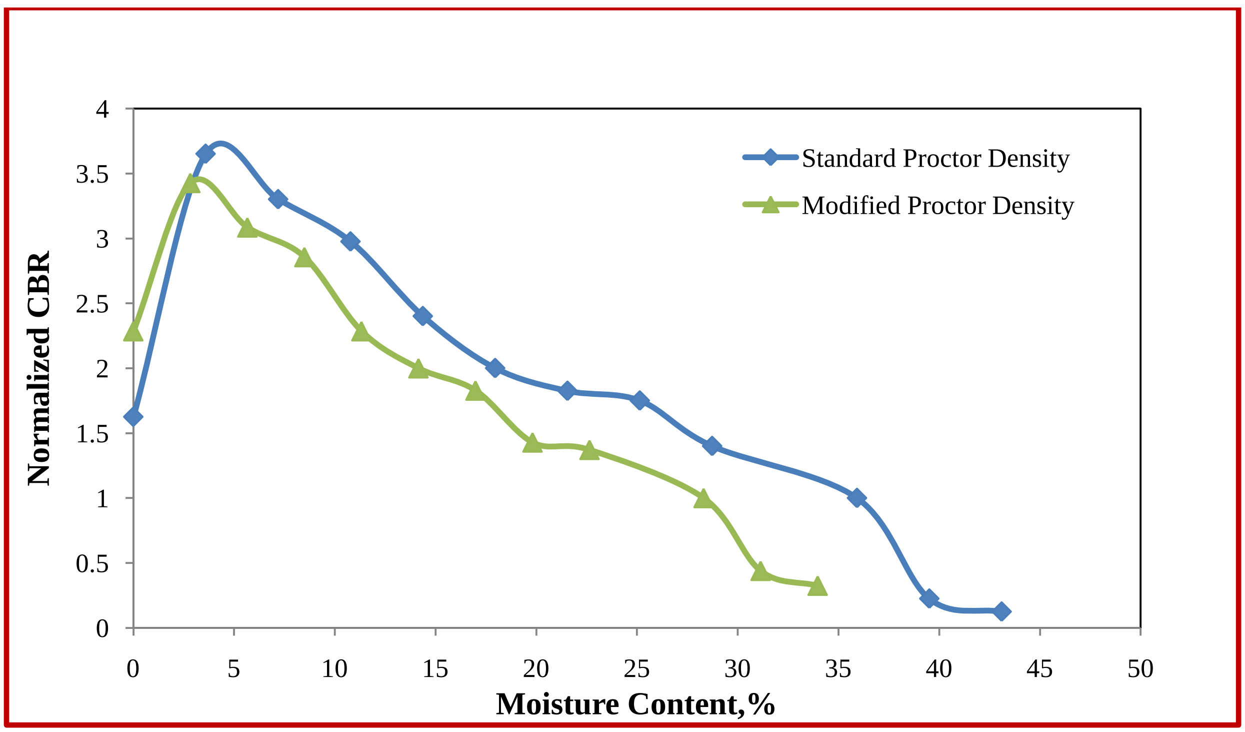

Fig. 4.39 Variation of Normalized CBR with moisture content.

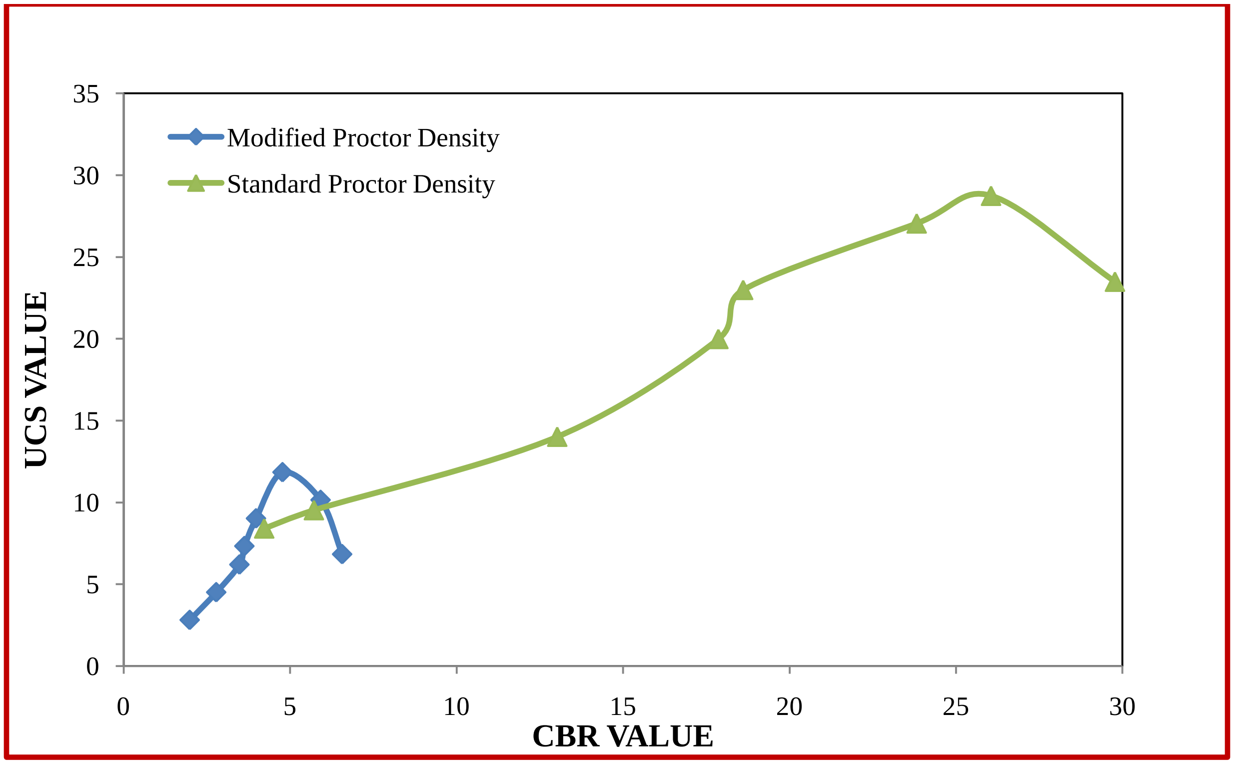

Fig.4.40 Relationship between UCS versus CBR value.

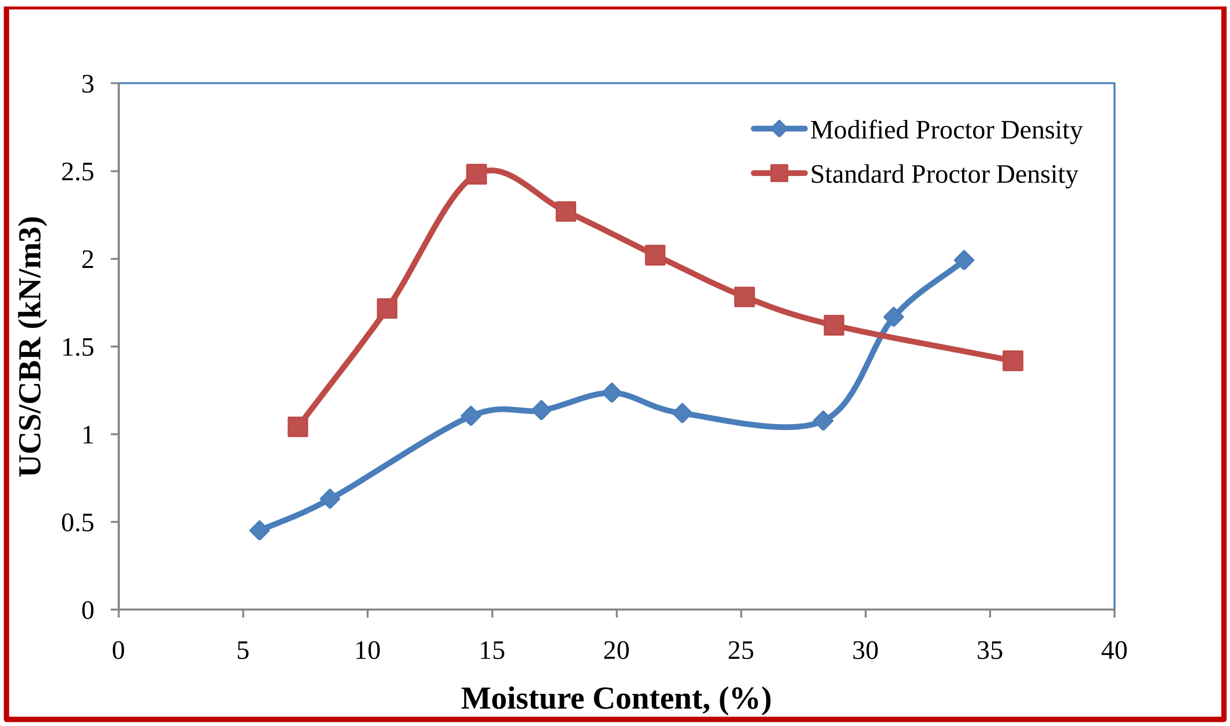

Fig 4.41 Variation of UCS/CBR with moisture content.

4.3.4.2 Effect of Fibre Content

The bearing resistance of the pond ash specimens reinforced with two different sizes of fibres that is 6mm and 12mm length was determined for specimens compacted to standard and modified proctor density with different percentage of fibre (i.e. 0.2%, 0.3%, 0.4%, 0.5%, 0.75%, and 1.0%). These tests were done in a standard CBR mould with a surcharge load of 2.5kg. Typical load versus penetration curves of reinforced (6mm fibre) pond ash specimens at standard and modified proctor density are given in Fig.4.42 and Fig.4.43 respectively. Similarly, Fig.4.44 and Fig. 4.45 shows load versus penetration curves of reinforced (12mm fibre) pond ash specimens at standard and modified proctor density respectively. Variation of bearing resistance with fibre content for reinforced (6mm and 12mm fibre) pond ash specimens at different strains level are presented in Fig. 4.46, Fig.4.47 and Fig.4.48, Fig.4.49 for samples compacted to standard and modified proctor density respectively. The bearing resistance of specimens is found to increase with the fibre content. However, the rate of increase of strength with fibre content is not uniform. At low strain levels the bearing resistance is found to remain almost constant with fibre content. However at higher strain level the bearing resistance is found to increases substantially with increase in fibre content. This shows that to mobilize the strength of fibre higher strain is required furthermore; it is observed that for a given compacted density an increase in fibre content results in decrease of initial stiffness whereas the failure strain increases. This indicates that inclusion of fibre gives ductility to the specimens. It can further be notice that reduction in post peak strain of a reinforced sample is comparatively lower than the unreinforced sample. Randomly oriented discrete inclusions incorporated into granular materials improve its load – deformation behavior by interacting with the soil particles mechanically through surface friction and also by interlocking. The bonding and interlocking between the granular particle and reinforcement facilitates the transfer of the tensile strain developed in the mass to the reinforcement and thus, the tensile strength of the reinforcement is mobilized and helps in improving the load capacity of the reinforced mass. The test result shows that the failure strain of reinforced specimen's increases with fibre content both for standard and modified proctor density. The plots also reveal that at given compacted density and fibre content, the 12mm size fibre gives higher strength than 6mm size fibres. The fibres modifies the stress condition in the specimens and transfer the shear along the failure plane to the surrounding mass by combined effect of adhesion and friction between the fibre and ash particles. For shorter fibres (6mm) sufficient anchorage to fibre might not be developed leading to pull-out failure and lesser mobilization of fibre capacity. In the present case only two fibre lengths have been tried. However it is expected that for given compacted density an optimum fibre length can be arrive at, which mobilizes the optimum strength of the fibre.

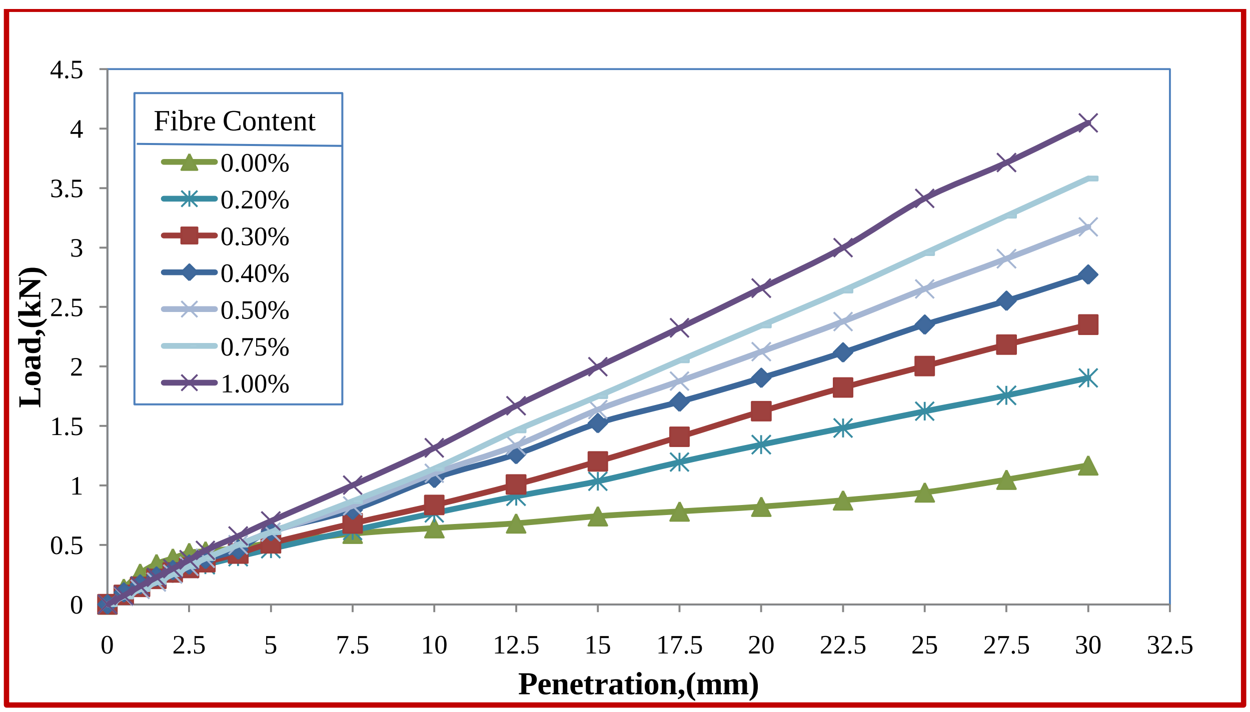

Fig.4.42 Typical load versus penetration curves of reinforced (6mm fibre) pond ash specimens at standard proctor density

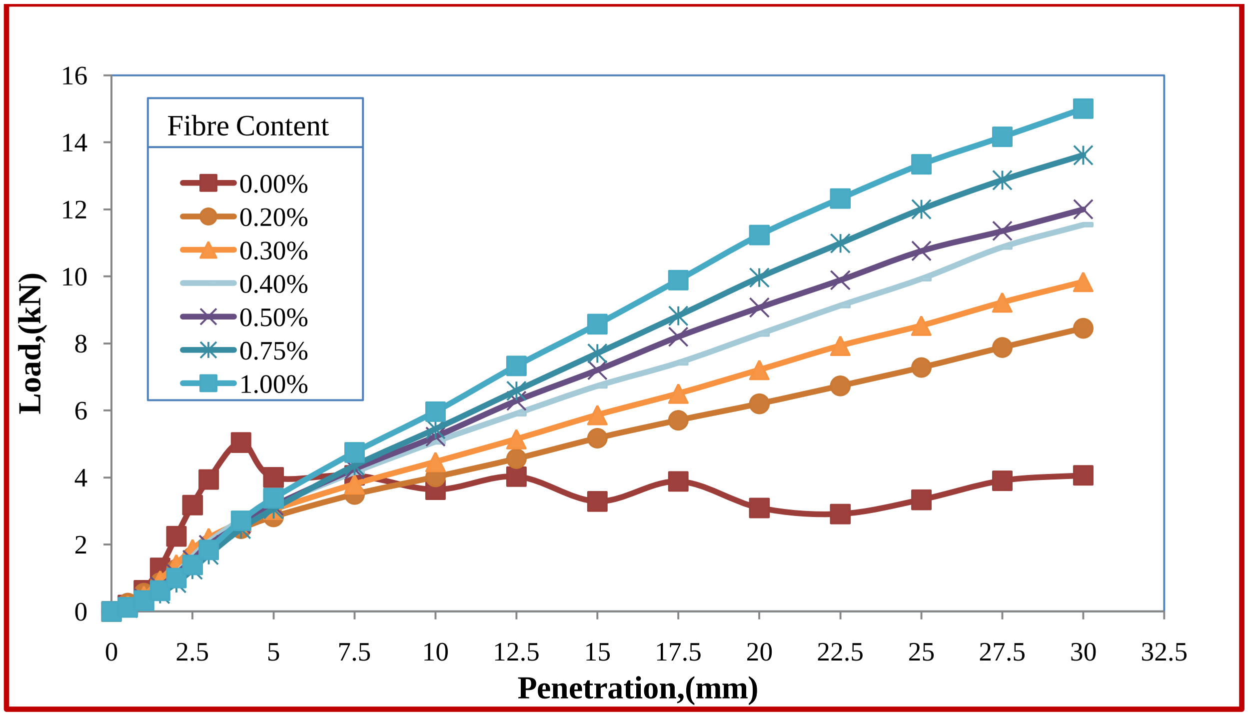

Fig.4.43 Typical load versus penetration curves of reinforced (6mm fibre) pond ash specimens at modified proctor density

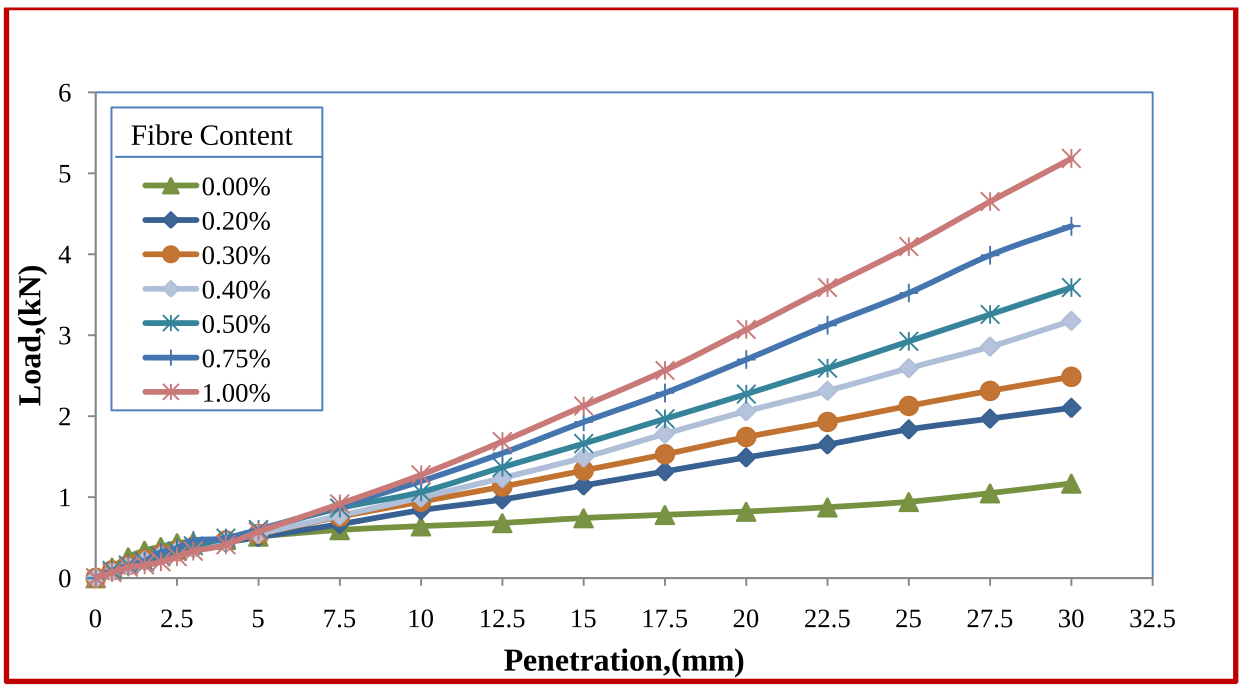

Fig.4.44 Typical Load versus Penetration curves of reinforced (12mm fibre) pond ash specimens at standard proctor density

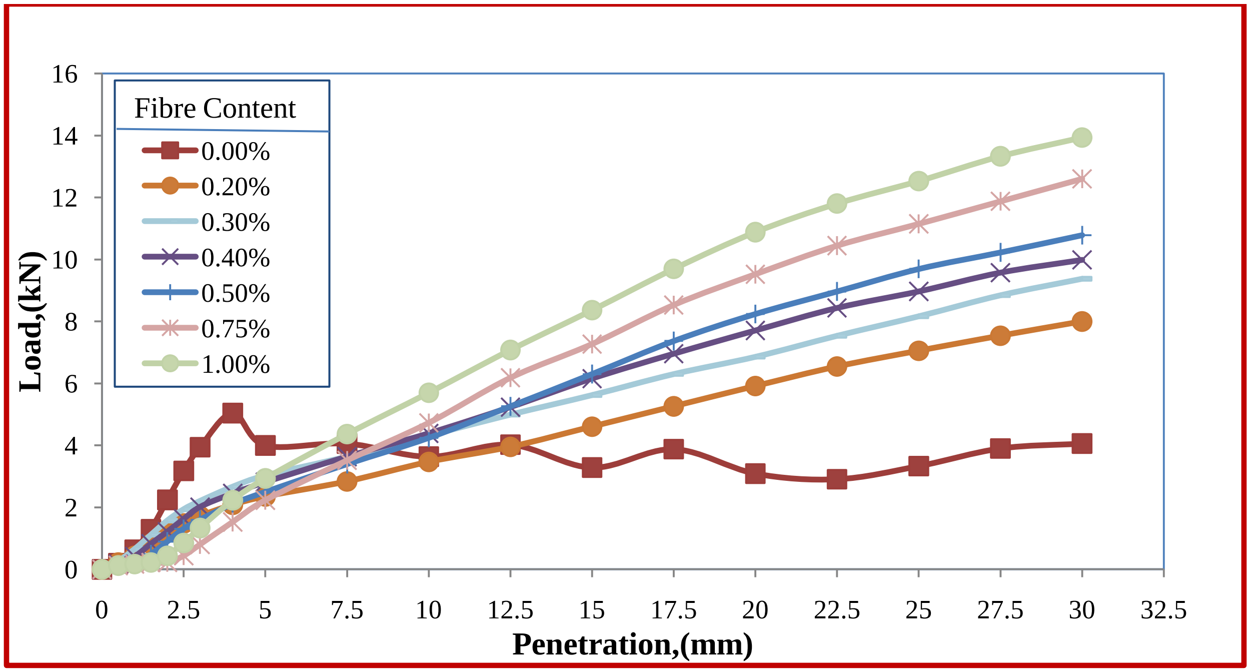

Fig.4.45 Typical Load versus Penetration curves of reinforced (12mm fibre) pond ash specimens at modified proctor density

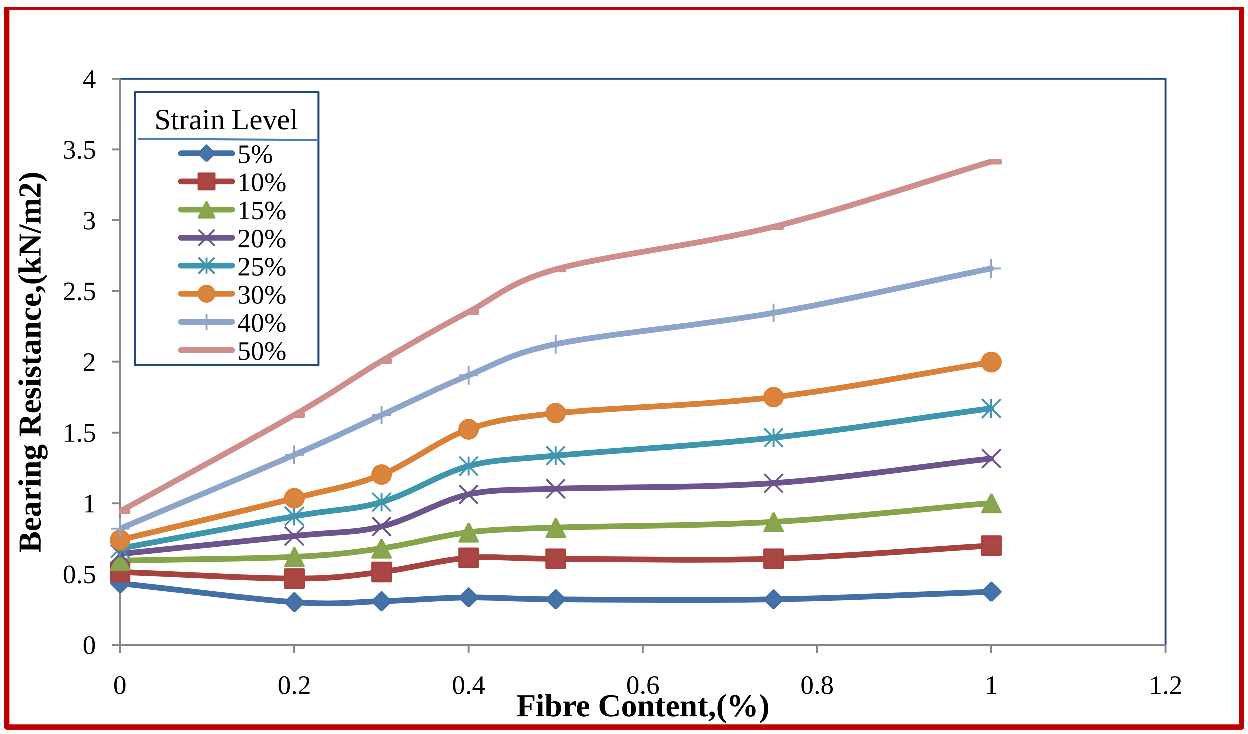

Fig.4.46 Bearing Resistance versus Fibre Content curves for reinforced (6mm fibre) pond ash of different strain level at standard proctor density

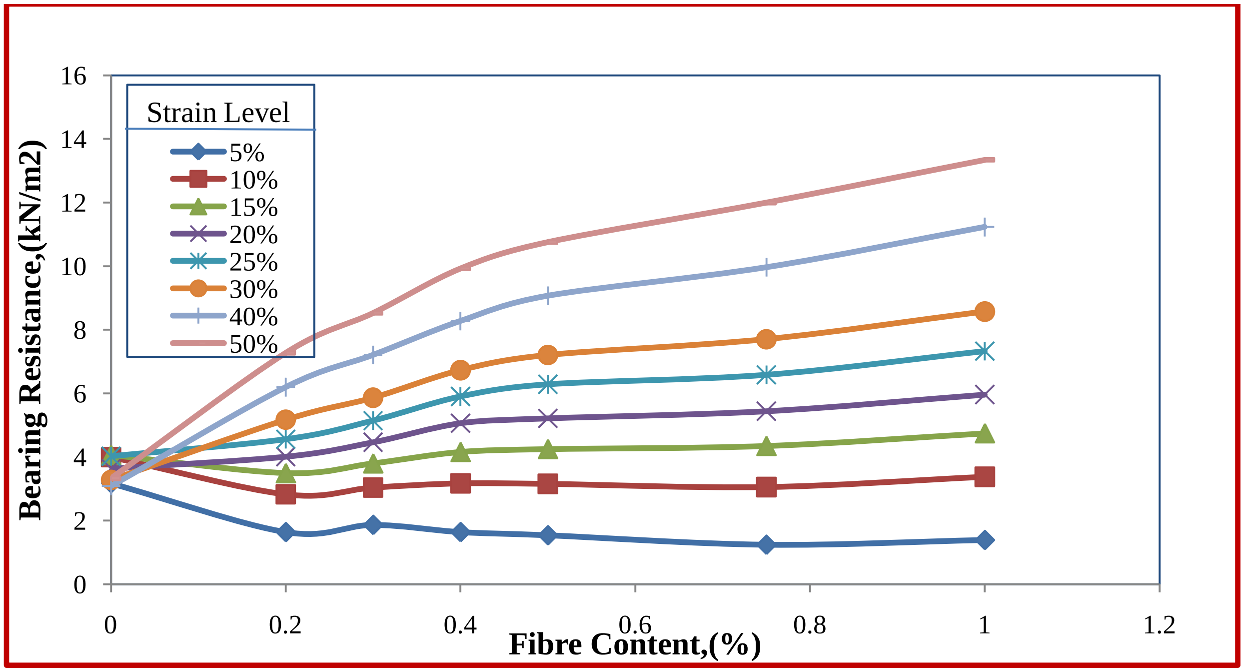

Fig.4.47 Bearing Resistance versus Fibre Content curves for reinforced (6mm fibre) pond ash of different strain level at modified proctor density.

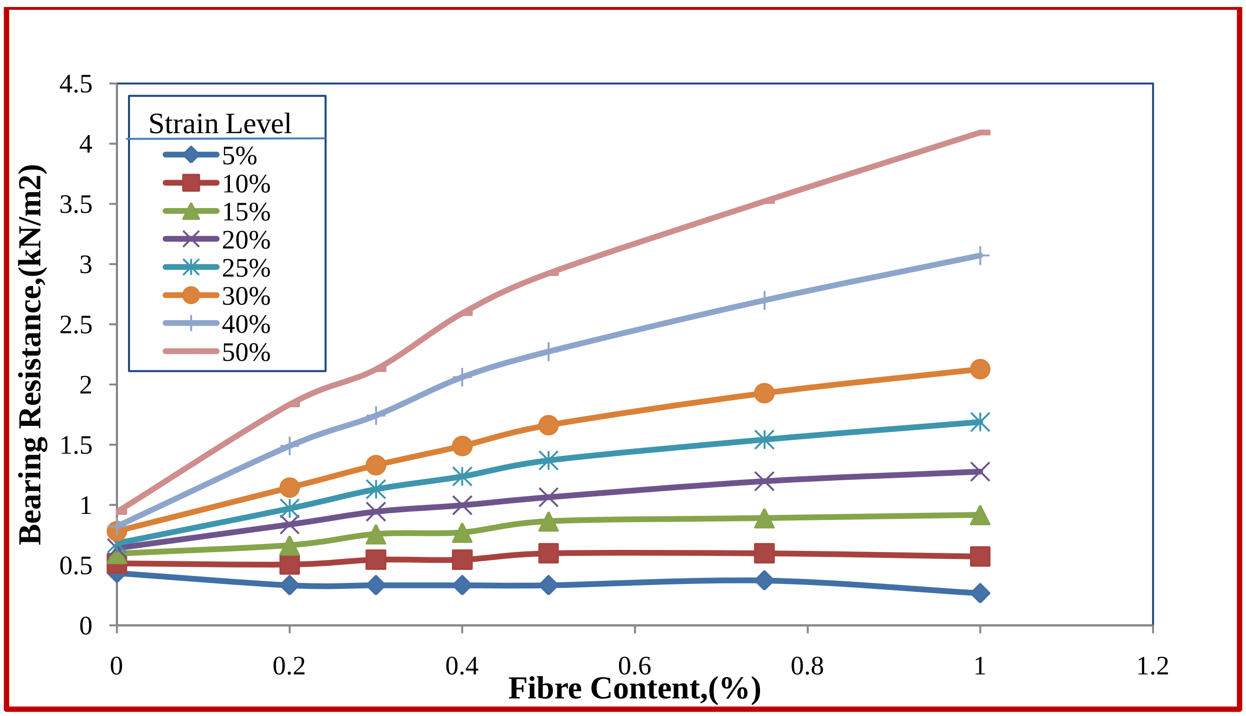

Fig.4.48 Bearing Resistance versus Fibre Content curves for reinforced (12mm fibre) pond ash of different strain level at standard proctor density.

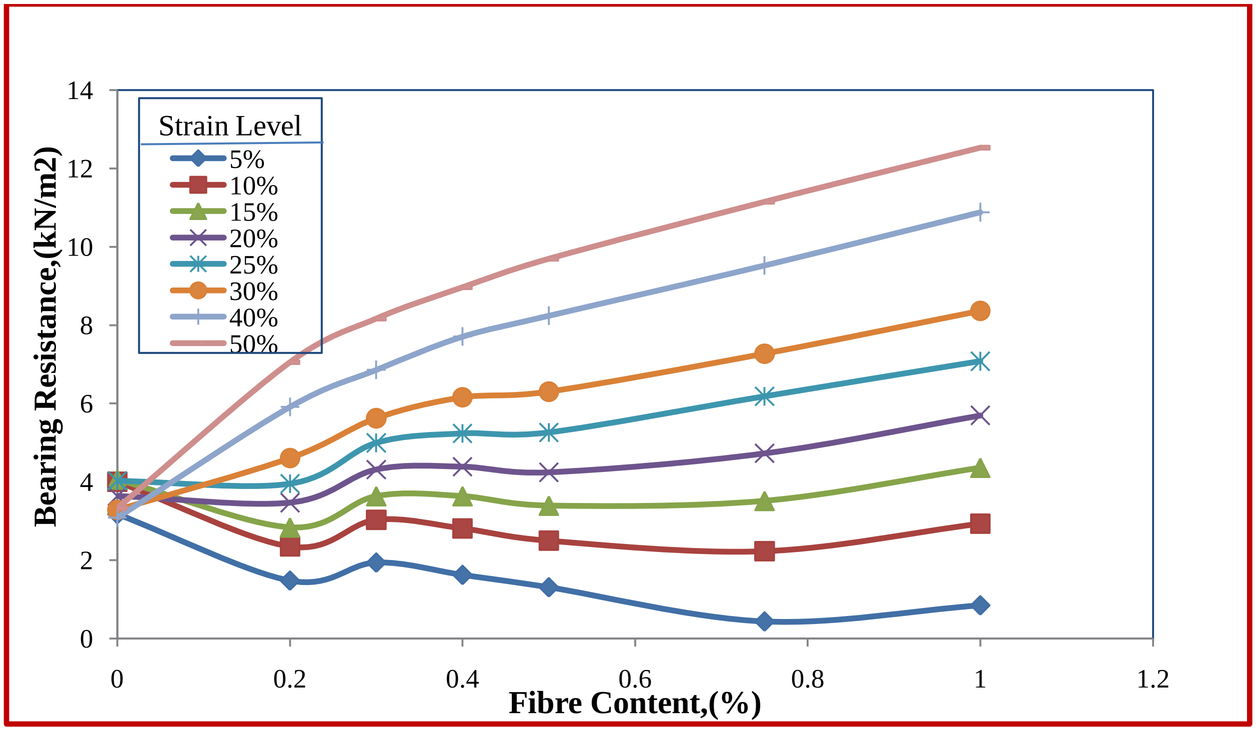

Fig.4.49 Bearing Resistance versus Fibre Content curves for reinforced (12mm fibre) pond ash of different strain level at modified proctor density.

CHAPTER-5
CONCLUSION

CONCLUSION

- The pond ash consists of grains mostly of fine sand to silt size with uniform gradation of particles. The specific gravity of particles is lower than that of the conventional earth materials.
- An increase in compaction energy results in closer packing of particles resulting in an increase in dry density where as the optimum moisture content decreases.
- Dry unit weight of compacted specimens is found to change from 10.90 to 12.70kN/m^3 with change in compaction energy from 357 to 3488kJ/m^3, whereas the OMC is found to decrease from 38.82 to 28.09%. This shows that pond ash sample responds very poorly to the compaction energy.
- Both the unit cohesion and angle of internal friction increase with increase in compaction energy. A nonlinear relation between these parameters is found to exist.
- The value of unit cohesion increases with degree of saturation up to the OMC and thereafter the same decreases. The highest value of unit cohesion occurs at OMC for samples compacted both at standard and modified densities. However, there is a continuous decrease of angle of internal friction value with degree of saturation. Initially there is a sharp decrease which gets stabilized at moisture contents higher than OMC.
- The unit undrained cohesion of reinforced specimens is found to increase with the fibre content. However, the rate of increase of unit undrained cohesion with fibre content is not linear. Initially the rate of increase is high thereafter the increase in unit cohesion is not that prominent.
- The plots also reveal that at given compacted density and fibre content, the 12mm size fibre gives higher strength than 6mm size fibres. The fibres modifies the stress condition in the

specimens and transfer the shear along the failure plane to the surrounding mass by combined effect of adhesion and friction between the fibre and ash particles.

- When the percent of water content reduces from the optimum moisture content the unconfined compressive strength increases at a sustained degree of saturation of 13% and 14 % and then, decreases in standard and modified proctor density, it is due to the added water lubricates the surface of ash particles.
- The failure stresses as well as initial stiffness of samples, compacted with greater compaction energies, are higher than the samples compacted with lower compaction energy. However the failure strains are found to be lower for samples compacted with higher energies. The failure strains vary from a value of 0.75 to 1.75%, indicating brittle failures in the specimens.
- A linear relationship is found to exist between the compaction energy and unconfined compressive strength.
- The UCS value is found to change from 1.2 to 17.0kN/m^2 with change in compaction energy from 357 to 3488kJ/m^3 indicating that the strength can be modified suitably by changing the compactive effort. It revealed from the test results that a linear relationship exists between the initial tangent modulus with unconfined compressive strength and deformation modulus.
- The trend observed in the CBR value with moisture content is very much similar to that observe with unconfined compressive strength value of specimens. This shows that for a given compacted dry density higher unconfined compressive strength as well as CBR value can be obtained with moulding water content much lower than the OMC value. This highlights the influence of degree of saturation on the strength of compacted pond ash specimens.

- The bearing resistance of specimens is found to increase with the fibre content. However, the rate of increase of strength with fibre content is not uniform. At low strain levels the bearing resistance is found to remain almost constant with fibre content.
- However at higher strain level the bearing resistance is found to increases substantially with increase in fibre content. This shows that to mobilize the strength of fibre higher strain is required furthermore; it is observed that for a given compacted density an increase in fibre content results in decrease of initial stiffness whereas the failure strain increases.
- This indicates that inclusion of fibre gives ductility to the specimens. It can further be notice that reduction in post peak strain of a reinforced sample is comparatively lower than the unreinforced sample.

Hence, the strength parameters achieved in the present study is comparable to the good quality, similar graded conventional earth materials. Hence, it can be safely concluded that pond ash can replace the natural earth materials in geo-technical constructions.

CHAPTER-6
SCOPE FOR FURTHER STUDIES

SCOPE FOR FURTHER STUDIES

For effective functioning of structures made up of reinforced pond ash, some more aspects have to be investigated.

- ✓ Effect of aspect ratio that is different fibre length on strength parameters and to arrive at an optimum value.
- ✓ Compressibility and Consolidation characteristics of compacted pond ash.
- ✓ Bearing capacity of surface and embedded foundations.
- ✓ Effect of other natural and synthetic fibres on geo-engineering properties.
- ✓ Liquefaction succesbility of fibre reinforced pond ash.
- ✓ The decay of organic fibres, creep effect in fibres to be studied.
- ✓ The environment aspects arising out of the leachate from the compacted pond ash.

CHAPTER-7
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